KNAPP'S CHEMICAL TECHNOLOGY.

TECHNOLOGY;

OR, CHEMISTRY APPLIED TO THE ARTS AND TO MANUFACTURES.

BY DR. F. KNAPP,

Professor at the University of Giessen.

EDITED, WITH NUMEROUS NOTES AND ADDITIONS, BY

DR. EDMUND RONALDS, AND DR. THOMAS RICHARDSON.

FIRST AMERICAN EDITION, WITH NOTES AND ADDITIONS,

BY PROFESSOR WALTER R. JOHNSON.

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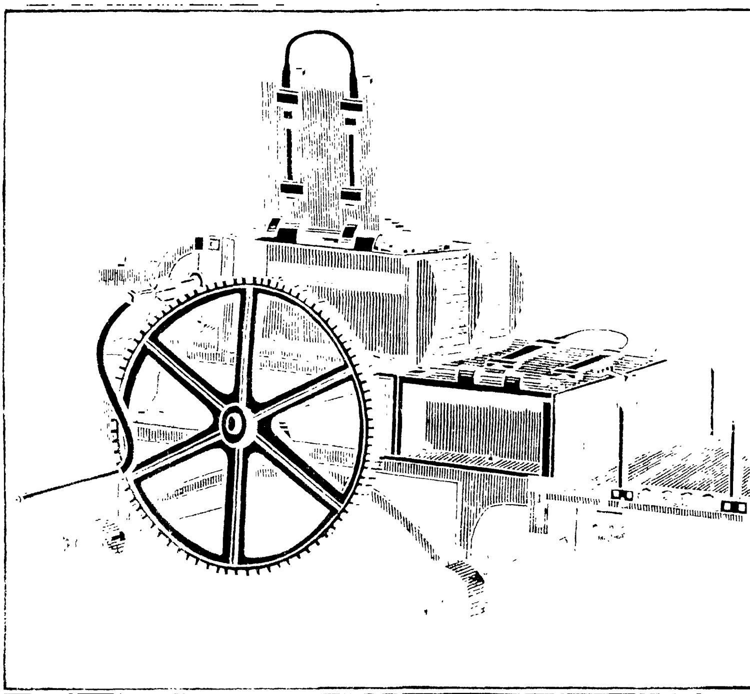

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AND

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OF NEWCASTLE-ON-TYNE.

FIRST AMERICAN EDITION, WITH NOTES AND ADDITIONS,

BY PROFESSOR WALTER R. JOHNSON,
OF WASHINGTON, D. C.

VOL. II.

ILLUSTRATED WITH

TWO HUNDRED AND FORTY-SIX ENGRAVINGS ON WOOD.

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PREFACE BY THE ENGLISH EDITORS.

The first section of our present volume embraces one of the most ancient and interesting branches of manufacture, namely, the manufacture of glass. It is followed by that of earthenware, with which, in a chemical point of view, it has much in common. The former has recently been relieved in this country from the vexatious restrictions of the excise laws, and already stands forth a bright example of the wisdom of modern legislation in removing all fiscal regulations from trade. Its rapid development, the numerous valuable practical improvements introduced in its manufacture, and the daily novel applications which are being made of it to the purposes of life, are so many proofs of the policy of leaving manufactures in a free and natural state. The baneful influence of previous control still lingers in that branch known as flint-glass, in which the habits and prejudices of the consumers, engendered by long usage, compels the manufacturer to employ a most expensive article in its preparation, long dispensed with in foreign productions. One impediment to the full development of this branch of manufacture still remains in the duty on windows, which we hope will shortly be repealed, and by increasing the facilities for obtaining pure air and ventilation, will prove an important step towards the improvement of public health.

Our Author's account of this branch of manufacture has been found quite insufficient to afford an idea of the nature of the operations in the English glass-houses, and we have consequently found it necessary to add here, as, also, in the other sections, much original matter, relating more particularly to English plans and processes.

The contrast which the earthenware manufactures present, in their extent, their general prosperity, and the wonderful cheapness of their productions, encourages the cheering hope that, ere long, this country will hold as distinguished a place for its glass manufacture as it already does in the case of the earthenware, where the name of Wedgewood makes many a continental production pass current in Europe.

In the present depressed state of the copperas trade, which is likely to continue, unless some new application of this article can be discovered, we hope our present volume will be found to contain some information of value. The American market for sulphate of iron having been nearly closed by their recent tariff, and the disuse of this substance in other branches of trade, leads us to believe that our manufacturers will do well to adopt the practice which prevails abroad in respect to the use of this article.

Our fourth group contains much information which is new to the great bulk of the English public, in which the recent researches of Fuchs, Kuhlmann, and others, are explained, and their application to the manufacture of cements and artificial foundations detailed at some length. We have also added one or two sections on the manufacture of magnesian salts, which are carried on to a very great extent in this country, in consequence of the peculiar facilities which it offers for the production of these articles.

While our friend, Dr. Knapp, is engaged in the preparation of another volume on articles of food, &c., we have undertaken that branch of Technology, more appropriately known as Metallurgy and the Chemistry of the Metals, to ensure the least possible delay in the completion of the entire work.

We have great pleasure in expressing our obligation to several gentlemen who have afforded us much valuable assistance in adding practical information connected with English manufactures. Amongst these, we are more particularly indebted to Mr. Apsley Pellatt and Mr. Charles Cowper, for information connected with the glass manufacture.

To Mr. Minton, of Stoke, and Mr. Singer, of Vauxhall, for facts connected with their respective manufactures, (English china and stone-ware.)

To Mr. Woolrich, of Birmingham, and Mr. Scanlan, for the accounts of the preparation of the commercial compounds of barytes and strontia.

No less, if not greater, expense has been incurred by our enterprising publisher in furnishing the illustrations for this than was the case with the first volume, and to him our grateful acknowledgments are also due, feeling assured that no exertion has been spared upon his part to render the present volume equally worthy of the public support enjoyed by the first.

London, *October* 14, 1848.

PREFACE BY THE AMERICAN EDITOR.

The very rich and copious fund of information contained in the original volume of which this is a republication, especially in those parts which relate to the two principal topics, glass and porcelain, has precluded the necessity of much extension in the details, in order to render the work useful to the American Reader. The manufacture of plate glass is yet scarcely introduced into America; and few works having extensive circulation here, can be cited as affording reliable and practical information to those who may desire to establish that

branch of industry. In other departments of glass manufacture the American artisan is not probably so far in the rear of the European as in that of making plate glass. In the making of cylinder window-glass, of pressed hollow glass, and many articles of furniture from the same material, the American glass houses appear to take a more active part, and several ingenious American inventions which we have introduced, and which are connected with these branches of art, prove that the intense activity of the American inventive genius has not been dilatory in applying itself to this department of manufactures.

In the second division, that which treats of the manufacture of alum, green vitriol, and fuming oil of vitriol, will be found a great number of data useful to the American Chemist, by an attentive study of which, the manufacturers of our country may cease to rely on foreign supplies for those important articles.

In many coal workings of the United States—anthracite as well as bituminous—the shales are largely impregnated with sulphuret of iron, and the observations found at page 181, will apply with full force to their heaps of waste. These heaps, instead of being made sources of profit, as they might be by certain cheap and simple arrangements for economizing the results of their decomposition (for which instructions are given in this volume), are now worse than useless.

In the third group, that embracing clay-wares, pottery, and porcelain, the information will be found no less opportune than that respecting plate glass. The various machinery and operations adapted to porcelain manufacture are so graphically set forth, and so clearly illustrated, that a comprehension of all the details should seem to present no difficulty. In many parts of our primitive geological formations, the materials for porcelain are already known to exist.

In the branch of manufactures embracing stoneware, bricks, and similar productions of the so-called ceramic arts, many full and interesting details will be found, more or less new to American artisans. In this department also, the editor has deemed it proper to make a few additions suitably illustrated. Some brick presses in extensive use may be noted as among the number.

Acknowledgments are due to the commissioner of patents, and other officers of the United States Patent Office, for opportunities of selecting these and some other illustrations contained in this volume.

In regard to hydraulic cements and mortars, the information of the original work has been augmented by the addition of numerous results deduced by Col. J. G. Totten, U. S. Engineer, from his own experiments on cements, mortars, concretes and groutings, and published in his edition of the essays of Treussart, Petot and Courtois. These will commend themselves to the attention of the engineer and builder as well as of the general inquirer after useful, practical information.

The portions added by the American editor are, in general, designated in the same manner as in the former volume, by brackets, thus [ ].

The English editors added very largely to the body of Professor Knapp's work, besides giving notes, and an appendix which included a number of important illustrations. Their additions to the text were accompanied by a single engraved plate, containing numerous figures illustrating the manufacture of glass. These have all been changed to the fine wood engravings adopted for this work, and appear in their proper places, greatly facilitating reference. The articles constituting the appendix of the English edition have been distributed to their proper places in the body of the work; so that all the matter pertaining to each division is brought into view before proceeding to a subsequent group. These changes, together with the new figures added, will, it is hoped, leave nothing to be desired either in regard to the number of illustrations or the facility of using them. The execution of the cuts will speak for itself.

In the great extension which has of late years been given to the arts in our country, the chemical department of technology may appear to have received less consideration than its relative importance might seem to demand, or its cultivation in foreign countries might lead us to expect. As an index to the relative advancement in this and other branches of art, we may cite the number of inventions which have been brought out by the ingenuity of our citizens in relation to this and other subjects of improvement. From the foundation of the American Patent Office, in 1793, down to the 1st of January, 1849, there had been issued 16,208 patents. Of this number, those which relate to the subjects mainly treated of in the two volumes of Chemical Technology, which we have now placed before the American reader, embrace 2868 patents. Hence 17.7 per cent. or a little more than one-sixth of the whole inventive activity of the country has been directed towards the subjects of heating and illumination; culinary apparatus, the preparation of fuel; chemical processes, manufactures and compounds; dyeing, color-making, distilling; soap and candle making; mortars, cements, stone and clay manufactures, pottery, bricks, and other building materials. Yet notwithstanding this amount of ingenuity, relating, directly or indirectly, to Chemical Technology, the progress of *discovery* in the science of Chemistry is constantly enlarging the field of *invention* in the same departments. While the principles of pure mechanics have long since been made generally intelligible, the science of Chemistry is still in the full vigor and activity of growth.

In conclusion, the editor will express the hope that the true friends and promoters of practical science, useful arts, and industrial economy, may find that the task of placing before American artisans the volumes now submitted to their inspection, has been performed in a manner not to derogate from the high character of the original work, or in any respect to compromise the dignity of science, while faithfully setting forth undeniable truths relative to the processes and economy of the arts.

WASHINGTON, *April* 10, 1849.

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TECHNOLOGY;

OR,

CHEMISTRY APPLIED TO THE ARTS

MANUFACTURES.

GROUP II.

CONTINUED.

GLASS.

Historical.—The origin of the art of glass-making is lost amongst the most ancient historical records. Mention is made of glass in the Bible about the time of Job, as a most valuable curiosity. The anecdote related by Pliny, that Phenician dealers in native soda, halting on the shores of the river Belus, and resting their culinary vessels over a fire, upon lumps of soda, caused the soda to unite with the sand of the shore and form glass—is a contradiction to all well-grounded experience. The heat of an open fire is totally insufficient for the production of real glass. Both Pliny and Strabo, however, give very accurate accounts of the glass-houses in Sidon and Alexandria, which prove, that not only the manufacture of glass was known at that early period; but also, that methods of cutting, grinding, gilding, and coloring were practised. Nevertheless, glass was always a most costly rarity amongst the ancients, and totally excluded from all applications of daily occurrence. It was only after the art of glass-making had been brought from its original seat to Venice, where the glass-houses which may still be seen on the island of Murano, were the only existing and justly celebrated manufactories of their time, that it became gradually and slowly disseminated, first into Bohemia, then into France, from thence to England, and lastly into Sweden. Colored window-glass is known to have existed in the third century, but only in churches; and yet, it is considered probable that the fragments dis-

covered in Pompeii are relics of blown window-glass.* The use of white glass for windows in dwellings, dates from a much later period; these were first [generally] introduced into England in the year 1180 and were not used in Vienna until the year 1458.

The establishment of the first glass-house in England occurred in the year 1557, and in Sweden the art was introduced by Germans in the year 1641.

It is also fully authenticated, that glass tears, or Rupert's drops, were known to the German glass-makers in the year 1625, although their properties were first explained by Chanut in 1656.

Colored glass, made in imitation of precious stones (*gemmæ vitreæ*), is mentioned by Pliny, by Trebellus Pollio in his "*Vitæ Galieni*," and by Tertullian, in whose time these imitations were as valuable as real pearls. The Emperor Hadrian received several colored glass goblets as a present from the Egyptian priests.

Although the art of glass making takes a prominent place in the technological literature of former times, being described at considerable length; for instance, in the seven books of Anton Neri, of Florence, in the work of Christopher Merret, an Englishman, and more particularly in the "*ars vitriaria*" of John Kunkel in the year 1679; yet the theoretical explanation of the process was only afforded by modern chemistry, and chiefly by the researches of Berzelius into the nature of silica.

Nature and Properties of Glass.—The substance that is termed *glass* is the product of fusion, at a high temperature, of silica (or sometimes of boracic acid), with different salifiable bases, as potash, soda, lime, magnesia, baryta, oxide of lead, oxide of tin, protoxide of iron, protoxide of manganese, alumina, and the peroxides of iron and manganese; the product solidifies after fusion in the form of a transparent mass, which is either colorless or not, according to the ingredients which it contains; it combines a great degree of hardness with the property of resisting the destructive action of air, water to a certain extent, and even that of the more powerful chemical agents. These valuable properties, notwithstanding they are coupled with great brittleness and fragility, render glass highly important as an article of domestic use, and also for the higher purposes of philosophical research. It is next to certain, that the rapid development of those sciences, which are based upon accurate observation and experiment, such as Astronomy, Natural Philosophy, Chemistry, and Physiology, could never have taken place without the knowledge of glass and its applications.

It is well known that silica acts the part of a powerful acid at the temperature of a red heat, and is capable of expelling carbonic acid, hydrochloric acid, &c., from compounds, and combining with the bases named above, giving rise to solid combinations. Glass, in short, belongs to the class of salts called silicates, and is an artificial pro-

* The Portland vase, the most beautiful specimen of colored antique glass, was found about the middle of the sixteenth century, enclosed in a marble sarcophagus, and deposited within the tomb of Alexander Severus, who died in the year 235.

duction of a similar character to those natural compounds, which occur so abundantly in nature; it differs, however, from these in one essential particular, that it possesses a distinctly non-crystalline structure; or is, as it is scientifically termed, *amorphous*. Glass may be said to bear the same relation to a natural silicate of like composition that melted sugar does to ordinary crystallized sugar.

Influence of the Constituents upon the Nature of Glass.—It is obvious that the properties of any kind of glass must be mainly dependent upon the nature of those bases which have been chosen for combining with silica in the process of fusion. The silicates of the *alkalies* are easy of fusion, and can consequently be produced at a moderately high temperature; they are, however, readily dissolved by water and decomposed by acids, and would, therefore, constitute by themselves a useless glass. The same applies, although in a less degree, to the silicates of the *earths*, as, for instance, to silicate of lime. The oxides of the more weighty metals, also, oxide of lead, for example, are easily attacked in this kind of combination, by substances possessing some degree of affinity for the base. The corresponding compounds of alumina offer the greatest resistance to decomposing agencies. Whilst the former, the silicates of potash, soda, lime, lead, &c., almost invariably retain the amorphous state on cooling, the difficultly fusible silicate of alumina, has a great tendency to acquire a crystalline structure, and this property unfits the glass for ordinary purposes. By combining the simple silicates with each other, however, experience has pointed out a method of compensating or mutually destroying these conflicting properties, and producing a substance which neither loses its amorphous structure too readily, nor too easily suffers decomposition. In fact, all ordinary glass (with the exception of those varieties specially employed on account of their solubility) is a combination of several silicates, or is a double silicate, and its properties and applicability are due to this, its compound nature. The properties of the simple silicates are, nevertheless, very distinctly marked in glass of this kind, and the most prominent characters of compound glass can always be traced to the preponderating influence of one or other of the bases. A knowledge of the influence of these bases is of the highest importance to the glass manufacturer, and the experience gained upon this part of the subject is chiefly as follows:

Potash and *soda* render the glass easy of fusion, and the former is the more efficacious. A more brilliant lustre results from the use of soda, but at the same time a bluish-green tint is communicated to the glass. No coloring action is exerted by potash, but the brilliancy of the glass is somewhat diminished by it.

Lime increases the hardness of glass, and adds more to its lustre than the alkalies. It exerts less influence in rendering the glass easy of fusion, and imparts no color to the produce, as is also the case with *alumina*, which, of all the ingredients, increases the difficulty of fusion the most, so that, when present in a certain very slight excess, the glass is enabled to resist the heat of the furnace.

Oxide of Lead exerts a directly opposite action to alumina, being

a prominent ingredient in the easily fusible varieties, which are also characterized by great softness, a high degree of brilliancy, perfect absence of color, and by the property of refracting light more powerfully than any other kind.

Barytes exerts a similar, although less energetic action.

The oxides of iron and of manganese also belong to that class of bodies which render glass easily fusible, but do not materially affect its lustre. The presence of iron in the state of protoxide, which it is difficult to prevent, is objectionable in those varieties of glass which are intended to be colorless, or nearly so, as it imparts rather a deep grass-green tint. The yellowish-brown color produced by the same quantity of iron in the state of peroxide, is, on the contrary, much less intense; when, therefore, the protoxide of iron contained in a specimen of glass is sufficient to communicate a distinctly green tint, and can by any means be converted into peroxide, the yellow color of the latter is so faint as to be hardly, if at all, perceptible to the eye.

Glass, colored green by protoxide of iron, can consequently be almost completely discolorized by oxidation. With manganese the effect is precisely opposite, and peroxide of manganese (MnO_2) is used for removing the color from glass containing the protoxide of iron. The peroxide is converted in this process into protoxide (MnO), which imparts no color; but if any excess has been employed, it becomes reduced at a red heat to deutoxide (Mn_2O_3), and produces a deep amethystine-red glass.

The other heavy metallic oxides, as those of gold, silver, copper, give rise to a great variety of very intense colors, and are consequently used in the manufacture as pigments, and of these and of their application we shall treat in the sequel.

It follows as a general conclusion from what has been stated, that those varieties of glass which possess the highest degree of lustre and power of refraction, will also be the softest (*i. e.* the most easily scratched). They are likewise those which exhibit the highest specific gravity (from 2.8 to 3.6), and, as might be deduced from that circumstance, they—at least as far as the colorless glasses are concerned—are those which contain bases with a very high equivalent or atomic weight (oxide of lead, baryta). Those bases, on the contrary, which render the glass hard and durable, appear to produce little lustre or power of refraction; the specific gravity of these varieties lies between 2.37 and 2.56. Strictly speaking, the alkalies, lime and oxide of lead, are the only bases expressly contained in the mixture for the manufacture of glass (without reference to the different coloring and discoloring matters). Magnesia sometimes accompanies the lime, and enters, but in small quantity only, into the composition of the glass. Alumina and oxide of iron are in like manner only casual constituents of the glass, being contained as impurities in the other ingredients. Even in those cases where these two bases enter in larger quantities into the composition of glass, they are never expressly added to the mixture; but are always derived from the impure materials. Thus, in the manufacture of ordinary bottle-glass, where

color is of no moment, materials containing iron and alumina are employed. The origin of the small quantity of alumina which is found in glass that should properly be free from it, must be traced to the sides of the pots or crucibles in which the glass has been fused.

The Mixture of Ingredients Compared with the Composition of the Glass.—The choice of the bases to be employed in the manufacture of glass must be guided by the purposes which the glass is destined to serve, and the selection of these will vary, according as the glass is intended for the optician, for general grinding and cutting purposes, for ordinary or better kinds of vessels, for mirrors or window-panes, &c. As glass is a true chemical compound, a genuine salt, the constituents of which are combined in definite proportions, it would be natural to suppose that a certain kind of glass could only be produced by the fusion of its ingredients in the same unvarying proportions. Just as ordinary borax is obtained in all cases, and under all circumstances, by the saturation of boracic acid with the same quantity of soda: as alum is always produced from the same relative quantities of sulphuric acid, alumina and sulphate of potash; so, we should be inclined to conclude, the same kind of glass must always result from the fusion of silica with the same bases in the same proportions. This, however, is practically not the case; for glass of very nearly the same nature is prepared in different glass-houses from very different mixtures of ingredients. The practice in mixing the ingredients also, is never founded upon the law of equivalents, and dates in almost every case from a much earlier period than the knowledge of that law. Nevertheless, the mixtures so prepared, when certain very wide limits are not exceeded, produce after fusion very perfect compounds from which no one of the elements of the mixture is excluded. The cause of this apparent contradiction may be traced to the following circumstances: In the first place, silica is capable of combining with the same base in variable proportions; a simple silicate, a bisilicate and a sesquisilicate of soda can all be produced; one equivalent of soda can even be fused together with 9 equivalents of silica in a blast furnace, and the formation of glass is only stopped by the difficulty of fusion, when 15 equivalents of silica have entered into combination with the soda. Besides, the capacity of silicic acid for taking up soda is, although only apparently, heightened at an elevated temperature; the acid silicates are much more difficultly fusible than those which contain a larger proportion of base, so that a glass mixture is easy of fusion in proportion to the small quantity of silica or large quantity of base which it contains. It is hence obvious that the temperature of fusion will aid in counteracting the deficiencies in the proportions of the mixture. Thirdly, the silicates of which glass is composed are capable of dissolving each other in all proportions at a high temperature, and also of entering into chemical combination, so that the different glasses are only solidified solutions, or chemical combinations of less complex silicates.

Another fact which tends to explain the apparent contradiction of a similar product being obtained from different mixtures, is, that the

alkalies in the state of carbonates, and particularly as chlorides, cease to be so perfectly non-volatile, at the temperature of the glass furnace, as they are usually assumed to be. Their volatility is, indeed, so great that an appreciable loss is occasioned, and the inner sides of the furnace are attacked by the vapors. As an excess of base is thus removed by volatilization, so, on the contrary, the chemical affinity of the silica is so augmented by the temperature, that it is enabled to extract alumina from the substance of the pots and combine with potash, mechanically carried up as ash with the flame. In the opposite case (when an excess of base is contained in the mixture) the bases are enabled to take up silica from the same sources.

Durability and Difficulty of Fusion of Glass.—The difficult fusibility of the acid silicates, and the opposite properties of those which contain a larger proportion of base, are very important facts in connection with the manufacture of glass. Silicic acid itself is perfectly infusible in every furnace, but it acquires this property in a greater or less degree, according to the quantity of base with which it is mixed. Glass-makers, in short, call all the bases *fluxes*, and are well aware that the work is facilitated and fuel saved by increasing the amount of flux in the mixture; but at the same time they know that the addition of flux cannot exceed a certain limit, without detriment to the durability of the glass. When glass is attacked under ordinary circumstances, it is always a result of the removal of base; chemical research has shown that the bases are in a state of very much less intimate combination, and are much more liable to be acted upon by external influences when they form the larger proportion of a silicate, or when the glass is of a basic character. These two considerations, economy on the one hand and quality of the product on the other, consequently oblige the glass manufacturer to observe a proper mean in the mixture of ingredients.

Under all circumstances, and when every precaution is taken in the manufacture, it is still impossible, as far as observation has shown, to obtain a glass which is practically incapable of being attacked. Pure, finely powdered glass taken from a tube or window pane and moistened with water, has been shown by Faraday and Bischoff to exhibit an alkaline reaction; sal-ammoniac precipitates flocculent silica from this solution, according to Fuchs. The same reaction occurs, according to Dumas, when water is boiled for some time in a glass vessel, and a troubled appearance, arising from insoluble silicate of lime, is occasioned at the same time. Griffiths extracted 7 per cent. of potash from flint-glass powder, by boiling it for weeks together with water, and repeatedly re-grinding and washing it. Hence it follows that ordinary glass cannot entirely withstand the action of water; although the influence exerted by this agent is comparatively unimportant and much less perceptible when the glass is not in the state of powder, and its natural surface is unimpaired. The best window panes, however, cannot altogether resist the action of the weather and the rain. The alkali is gradually extracted by atmospheric moisture and washed away, whilst a very thin layer of silica or of silicate of lime remains upon the surface, and exhibits a play of prismatic colors.

The external coating,* exhibiting the lustre of mother of pearl, which was observed on glass that had been dug from the earth with other relics of antiquity, was found by Griffiths to be pure silica. An observation of Colladon is very remarkable and difficult of explanation, who found pieces of glass taken from an old pit, 12 feet deep, both flexible and so soft that they could be kneaded and cut with a knife; glass of this kind, however, regained its hardness and frangibility by exposure for several hours to the air.

Acids naturally extract potash, soda, and lime, with much greater ease from glass, with the separation of gelatinous silica. Caustic alkalies exert an opposite action upon glass by dissolving its silica. A like effect has been attributed to ammonia, and thence it has been explained, why the panes of glass in stables are particularly liable to become coated with a thin layer exhibiting the play of colors mentioned above. Glass which contains oxide of lead is liable to blacken on exposure to air containing sulphuretted hydrogen, by the formation of sulphuret of lead; and when heated in a flame, the oxide of lead is frequently reduced and blackness is produced by the metallic lead.

The action of hydro-fluoric acid, the most powerful agent for the decomposition of glass, is quite peculiar. Glass is completely disintegrated by this acid with the formation of fluosilicic acid and double compounds of fluoride of silicon with the fluorides of potassium, fluorides of sodium, and fluorides of calcium, &c.

The production of glass and the method of working it, are dependent upon properties, which it is essential to become acquainted with in order to understand the nature of these operations, and it will therefore be proper to examine them more minutely.

Tough State of Fluidity. Brittleness.—At the most intense heat of which the furnace is capable, glass is tolerably fluid, possessing about the consistence of weak syrup. The possibility of casting or moulding glass, as well as its purification, depends upon this state of fluidity, as the impurities are then enabled to subside to the bottom, whilst the bubbles of gas escape from the surface. At a lively red heat, on the contrary, melted glass is an exceedingly tough, thick mass, possessing great ductility and capable of being drawn out into the finest threads or blown into the form of the thinnest hollow spheres; the usual method of working glass by *blowing* would be quite impracticable unless the mass possessed these properties. Two pieces of glass in this state can be united by simple pressure, or, as it were, soldered together with greater ease than soft wax.

The Cause of Brittleness.—When melted glass cools, the smallest particles of which always exhibit in the fluid state a tendency to arrange themselves in a regular manner and form crystals, no time is allowed the semi-fluid mass to follow this tendency, and the particles are forced, as it were against their inclination, to remain in that relative position towards each other, which they assumed during the working, or in other words, to form an amorphous mass. This forced relative position of the particles is greatest where the glass has been rapidly cooled; the interior of the mass is, therefore, not so subject to it as the surface, and this latter also contracts in a greater degree.

The outer layers are consequently in a state of tension with reference to those in the interior. It is obvious from these facts that there must be a want of uniformity in the attractions of the particles of glass for each other, that a tendency to subvert the force of cohesion has been induced in the mass, which the slightest impulse from without will be sufficient to carry out. This circumstance perfectly explains the brittle nature of glass, which sometimes rises to a very extraordinary pitch. If a drop of melted glass, for instance, is allowed to fall into cold water, it assumes the form represented in Fig. 1, which is well known from its great brittleness under the name of a Rupert's drop.

Fig. 1.

By merely breaking off the point, the tension is called into play, and the whole solid mass is instantly converted into a fine powder. In the same manner, a small angular grain of sand or piece of flint, when shaken in one of the Bologna phials,* shatters it in pieces, often with a slight explosion. Glass cooled in the air in tolerably thick masses exhibits very similar properties. A bottle for instance, or a tumbler, would be quite inapplicable to domestic uses on account of its great brittleness, if prepared under such circumstances. Special precautions are consequently necessary in practice to obviate this evil. The ready formed glass vessels are usually placed in an oven heated to a temperature just below that at which the glass softens, and the oven with all its contents is then gradually allowed to cool down to the temperature of the atmosphere. Although the brittleness of glass is not entirely obviated by this means, yet it is so modified that the vessels with a little care, can be used for all ordinary purposes. Sudden change of temperature or partial application of heat will cause the fracture of glass quite as surely as a blow.

Devitrification.—The more slowly glass is cooled, the more its brittleness is impaired, until at length the amorphous state entirely disappears, and the mass assumes a crystalline structure. The properties of glass cooled in this manner are remarkably changed, and this is of importance in a practical point of view. The first glass of this kind was produced and described by Reaumur. When glass vessels were placed in a crucible, and the unoccupied space in and about the vessel was filled up with a mixture of burnt gypsum and fine sand, and the whole then exposed and left to itself in an earthenware furnace during the burning, the following changes were observed in the glass when cool. The surface had lost its lustre, and the mass in a great measure its transparency; the fracture was dull and earthy, but at the same time fibrous, and of a silky lustre. In the middle, a portion of transparent unchanged glass was generally left, towards which the fibres converged.

* These are small portions of glass taken from the pot at the end of the pipe, and slightly inflated into the form of a long thin phial, with a very thick bottom, which is rapidly cooled in the air.

Dumas found in bottle-glass devitrified by Darcet:

Silica - - - - -	52.0
Potash - - - - -	2.0
Lime - - - - -	27.4
Alumina - - - - -	12.0
Oxide of iron, and of manganese - -	6.6
	100.0

It is evident from this, that the composition of the devitrified mass does not differ from that of the corresponding glass, more than the varieties of the glass differ amongst themselves (compare the analyses below); but the amount of potash is remarkably diminished. It, therefore, appears in this case, that the devitrification is not only attended by the formation of crystals, but also by a diminution in the amount of potash, and a consequent chemical transformation. Experience favors the assumption that difficultly fusible glass containing little alkali, like bottle-glass, is most easily devitrified.

The comparative analyses of the mass of glass itself, and of the crystalline portion, show, in the clearest possible manner, that such devitrification is frequently occasioned by the mass being broken up into different chemical compounds, one of which then assumes the crystalline form. When larger masses of glass are cooled slowly in the glass pots, a portion in the form of opaque crystals is frequently observed disseminated through the transparent matrix. Dumas has examined specimens in both states from the collection in the Polytechnic School; and others, from a glass-house in the Plauen'schen Grund (a valley near Dresden), have been analyzed by Kersten. They found:

	Kersten.				Dumas.			
	Crystalline portion.		Vitreous portion.		Crystalline portion.		Vitreous portion.	
		Oxygen		Oxygen		Oxygen		Oxygen
Silica - - -	58.8	30.54	60.39	31.40	68.2	35.46	64.7	33.64
Alumina - - -	3.3	1.54	6.10	2.84	4.9	2.28	3.5	1.63
Lime - - -	20.2	5.77	13.40	3.83	12.0	3.43	12.0	3.43
Protoxide of iron -	3.5	0.80	3.10	0.70	—			
" manganese	4.2	0.93	2.20	0.49	—			
Magnesia - - -	0.5	0.19	0.40	0.15	—			
Potash - - -	2.7	0.45	14.41	3.05	—			
Soda - - -	5.4	1.40			14.9	3.81	19.8	5.06

In the specimen analyzed by Kersten, the oxygen in the silicic acid is to that of the alumina, and to that of the other bases together:

In the crystalline portion as $30.54 : 1.54 : 9.54 = 20 : 1 : 6$.

In the vitreous matrix as $31.40 : 2.84 : 8.22 = 12 : 1 : 3$,

which proportions lead to the following formulæ:

For the crystalline portion $3SiO_3,M_2{}^*O_3+17(SiO_3MO)$.

For the vitreous matrix $3SiO_3,M_2O_3+9(SiO_3MO)$.

* M=1 equiv. of metal, as potassium, sodium, calcium.

The relations of the oxygen in the specimen analyzed by Dumas led to the same general fact; they were:

In the crystalline portion as 35.46 : 2.28 : 7.24=16 : 1 : 3.

In the vitreous matrix as 33.64 : 1.63 : 8.49=20 : 1 : 5,

whence are deduced the formulæ:

For the former $6SiO_3,M_2O_3+13(SiO_3,MO)$.

For the latter $3SiO_3,M_2O_3+17(SiO_3,MO)$.

and these render it obvious that both portions are distinct chemical compounds.

Reaumur's Porcelain.—The devitrified state frequently occurs during the operations of working as a consequence of repeated heating; it is evinced by a certain degree of opacity in parts of the mass, and the sudden appearance of a disproportionate degree of toughness, so that the blowers must be very cautious in preventing its occurrence, or the completion of the work in hand will be quite impracticable. It may, therefore, be generally asserted that devitrification must be ascribed partly to change in composition, and partly to crystallization. It is very remarkable that the brittleness of glass and its susceptibility of fracture from sudden changes of temperature are very much diminished by devitrification, so much so, that devitrified glass possesses these properties in a less degree even than porcelain. Reaumur endeavored to introduce a material of this kind in place of pottery, and it has been called after him Reaumur's porcelain; the idea is well worthy of more attention than has really been expended on it.

Classification of the Varieties of Glass.—The varieties of glass are usually classified according to their technical uses, a mode of division which is in some manner connected with their composition. We distinguish:

A. *Hohl glass*, or *bottle-glass*,* which comprises all glass worked into the form of vessels, &c. It is subdivided, according to the purity of the metal† of which it is composed, into:

a. *Ordinary bottle-glass*, consisting of silica, potash, or soda, lime, alumina and oxide of iron.

b. *Glass used for medicinal bottles*, composed of silica, soda, lime, some alumina, and a very little protoxide of iron.

c. *White bottle-glass* (in a limited sense), for bottles, tumblers, tubes; containing silica, soda or potash, and lime.

B. *Window-glass*, composed of silica, potash or soda, lime and alumina.

C. *Plate-glass*, composed of silica, soda or potash, lime and a little alumina. This variety only differs from the preceding by the greater purity and freedom from color of the materials.

D. *Flint-glass*, used for grinding, &c., composed of silica, potash and oxide of lead.

* As the term is ordinarily used, it does not apply to those kinds of glass that may be employed for similar purposes which contain lead in their composition; so that bottle-glass and crystal are thus in direct contrast with each other.

† Metal is the technical term given in England to glass before it is worked up into vessels.

E. *Crystal*, for optical purposes, composed of silica or boracic acid, potash and more lead than the preceding variety.

F. *Strass*. The mass composing the imitations of precious stones, consisting of silica, potash, with the largest amount of oxide of lead, and colored by various metallic oxides. The pigments used by artists in glass and porcelain, are also included under this head; they are easily fusible glass fluxes, consisting of lead and boracic acid, which can be colored in any manner that is required.

G. *Enamel*, composed of silica, soda and oxide of lead, but rendered opaque by oxide of tin or antimony.

Some of these varieties of glass are in themselves colored, as the dark brown or green bottle-glass; the light green bottle-glass, used by chemists; optical glass and the superior kinds for domestic use must be perfectly colorless; all the varieties mentioned can, however, be colored artificially.

Composition of the Varieties of Glass.—It has already been stated that all the constituents of glass are in a state of chemical combination. The individual constituents must, therefore, be united in equivalent proportions. These relations are sometimes apparently obliterated in consequence of different oxides replacing each other, but the regularity of the composition is always evinced by a simple relation between the collective amount of oxygen in the bases and that contained in the silicic acid. In the following summary of the analyses of glass, which have been published, this relationship is always indicated below.

BOTTLE-GLASS.

Analysts.	Berthier.			Dumas.	
Variety of glass.	1	2	3	4	5
Silica*	60.0	60.4	59.6	53.55	45.6
Potash	3.1	3.2	3.2	5.48	6.1
Soda			—	—	—
Lime	22.3	20.7	18.0	29.22	28.1
Magnesia	—	0.6	7.0	—	—
Barytes	—	0.9	—	—	—
Protoxide of manganese	1.2	—	0.4	—	—
Alumina	8.0	10.4	6.8	6.01	14.0
Oxide of iron	4.0	3.8	4.4	5.74	6.2
Oxide of manganese	—	—	—	—	—
Relation between the oxygen of the acid and the total amount of oxygen contained in the bases	5 : 2	?	7 : 3	2 : 1	4 : 3
Relation between the oxygen in the bases with 1 eq. of that element, and that contained in the bases with 3 eq. of oxygen	4 : 3	?	2 : 1	2 : 1	1 : 1

* Argillo is the name given to a vitreous compound manufactured at Hartford, Conn., and at Albany, N. Y., and used for tiles, panels, tables, knobs for doors, and furniture,

No. 1. Glass from Souvigny. No. 2. From St. Etienne. No. 3 From Epinac. No. 4. From Sèvres, near Paris. No. 5. From a unknown glass-house, but of French manufacture.

MEDICINAL GLASS.

Analyst.	Berthier.			
Variety of glass.	1	2	3	4
Silica	71.6	62.5	69.6	62.0
Potash	10.6	10.5	8.0	—
Soda	—	—	3.0	16.4
Lime	10.0	16.2	13.0	15.6
Magnesia	—	—	0.6	2.2
Protoxide of manganese	0.3	1.2	—	—
Alumina	3.0	4.5	3.6	2.4
Oxide of lead	1.5	2.5	1.6	0.7
Relation between the oxygen of the acid and the total amount of oxygen in the bases	6 : 1	7 : 2	9 : 2	5 : 1
Relation between the oxygen in the bases with 1 eq. of that element, and that contained in the bases with 3 eqs. of oxygen	2 : 1	7 : 3	3 : 1	9 : 1

All the varieties were of French manufacture.

WINDOW-GLASS.

Analysts.	Dumas.							Richardson.	Cowper.*
Variety of glass.	1	2	3	4	5	6	7	8	9
Silica	69·65	69.25	68.55	68.65	68.5	68.0	69.0	66.37	71.4
Soda	15.22	11.30	12.88	17.70	13.7	10.1	11.1	14.23	15.0
Lime	13.31	17.25	16.17	9.65	7.8	14.3	12.5	11.86	12.4
Alumina	1.82	2.20	2.40	4.00	10.0	7.6	7.4	8.16	0.6
Relation between the oxygen of the acid, and the total amount of oxygen in the bases	4 : 1	4 : 1	4 : 1	4 : 1	7 : 2	7 : 2	7 : 2	7 : 2	9 : 2

The numbers from 1 to 6 are of French origin. Nos. 7, 8 and 9 are English.

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the principal ingredients of which are silica, alumina, lime, and coloring metallic oxides. —Am. Ed.

* This specimen was the glass manufactured by Messrs. Chance, of Birmingham, and is remarkable for containing more silica and less alumina than any of the other varieties. Mr. Cowper also found 0.3 oxide of iron, and 0.3 oxide of manganese in this specimen of glass.

PLATE-GLASS.

Analysts.	Berthier.	Tassert.	Dumas.		Berthier.
Variety of glass.	1	2	3	4	1
Silica	72.0	76·0	75.9	73.85	68.6
Potash	—	—	—	5.50	6.9
Soda	17.0	17.0	17.5	12.05	8.1
Lime	6.4	6.0	3.8	5.60	11.0
Magnesia	—	—	—	—	2.1
Protoxide of manganese	—	—	—	—	0.1
Alumina	2.6	—	2.8	3.50	1.2
Oxide of iron	1.9	1.0	—	—	0.2
Relation between the oxygen in the acid and the total amount of oxygen in the bases	6 : 1	?	7 : 1	7 : 1	5 : 1

The last specimen was Venetian, the others were French glass.

DIFFERENT VARIETIES OF WHITE GLASS.

Analysts.	Berthier.	Gros.	Dumas.	Berthier.	Dumas.
Variety of glass.	1	2	3	4	5
Silica	71.7	71.6	69.4	69.2	62.8
Potash	12.7	11.0	11.8	15.8	22.1
Soda	2.5	—	—	3.0	—
Lime	10.3	10.0	9.2	7.6	12.5
Magnesia	—	2.3	—	2.0	—
Protoxide of manganese	0.2	0.2	—	—	
Alumina	0.4	2.2	9.6	1.2	—
Oxide of iron	0.3	3.9	—	0.5	2.6
Relation between the oxygen of the acid and the total amount of oxygen in the bases	6 : 1	6 : 1	4 : 1	4 : 1	5 : 1

1. Specimen of a goblet from Neufeld, in Bohemia. 2. Specimen from the same place. 3. Bohemian glass. 4. Specimen of easily fusible French glass tubing. 5. Specimen of crown glass.

CRYSTAL.

Analysts.	Berthier.			Dumas.	Faraday.
Variety of glass.	1	2	3	4	5
Silica	59.2	56.0	51.4	56.0	51.93
Potash	9.0	6.6	9.4	8.9	13.67
Lime	—	—	—	2.6	—
Oxide of lead	28.2	34.4	37.4	33.5	33.28
Protoxide of manganese	1.0	—	—	—	—
Alumina	—	1.0	1.2*	—	—
Oxide of iron	0.4	—	0.8	trace	—
Relation between the oxygen of the acid and the total amount of oxygen in the bases	8 : 1	8 : 1	6 : 1	6 : 1	6 : 1

1. From London, intended for optical instruments. 2. From Voneche in Belgium. 3. From Newcastle. 4. Of unknown origin. 5. From England.

FLINT-GLASS, STRASS AND ENAMEL.

Analysts.	Faraday.	Dumas.	Dumas.	Dumas.
Variety of glass.	Flint glass from Guinand.		Strass manufactured by Donault Wieland.	Enamel.
Silica	44.3	42 5	38.5	31.6
Potash	11.75	11.7	7.9	8.3
Lime	—	0.5	—	—
Ox. of Lead	43.05	43.5	53.0	50.3
Ox. of Tin	—	—	—	9.8
Alumina	—	1.8	1.0	—
Relation between the oxygen in the acid, and the total amount of oxygen in the bases	9:2	4:1	7:2	7:3

The following analyses by Peligot are quite recent.

	Bohemian glass.	Bohemian opal glass.	Venetian Aventurine.	Bohemian Mirror glass.
Silica	76	80.9	67.7	67.7
Potash	15	17.6	5.5	21.0
Lime	8	.7	8.9	9.9
Alumina	1	.8	—	1.4
Soda	—	—	7.1	—
Oxide of Tin	—	—	2.3	—
Oxide of Lead	—	—	1.1	—
Copper	—	—Metallic	3.9	—
Oxide of Iron	—	traces	3.5	—
	*100	†100.0	‡100.0	100.0

Mr. Rowney has lately analyzed the Bohemian hard glass tubing, so indispensable to chemists in the prosecution of researches in organic chemistry, and finds it to be essentially a silicate of lime and potash, in which the oxygen in the silicic acid is to that contained in the bases as 6 : 1. Analysis yielded:—

* The Bohemian flint-glass is distinguished from others by containing no lead.

† This glass is very similar to Hyalite, *muller glass*, a hydrate of silica (Thomson). The composition is remarkable: it is a simple silicate of potash, which, from being imperfectly melted, remains semi-transparent, with pieces of quartz dispersed through the mass. It does not attract moisture, and is not attacked by boiling water. It differs from Fuch's soluble glass, by containing 10 per cent. more silica.

‡ This glass contains also traces of magnesia and phosphoric, or boracic acid; the crystals appear disseminated through the mass, which is of a yellow tint, and transparent in thin sheets. The tin and iron obviously assist in the formation of the crystals of metallic copper, after which the tin becomes silicate of the protoxide; otherwise the glass would become opaque.

Silica	73
Potash	11.5
Soda	3.
Lime	10.5
Alumina, peroxide of iron, magnesia, and oxide of manganese	2.0
	100.0

It may, however, be remarked, that this tubing is by no means always of uniform composition, as all who have been much occupied with organic analysis will have found to their cost; some tubes being much more easily fusible than others.

The analyses clearly prove, that notwithstanding the great variety of constituents of which glass is composed, these are always combined in definite proportions: this is rendered more obvious when the empirical formulæ are deduced from the composition in 100 parts; thus, the composition in 100 parts of

Bottle-glass No. 5, corresponds to $KO+8CaO+2Al_2O_3+F_2O_3+8SiO_3$;
Window-glass No. 2 " " $3NaO+5CaO+12SiO_3$;
Plate-glass No. 1 " " $2NaO+CaO+6SiO_3$;
White crown-glass No. 5 " $KaO+CaO+3SiO_3$;
Crystal No. 2 " " $KaO+2PbO+8SiO_3$;
Flint-glass No. 2 " " $6KaO+9PbO+20SiO_3$;
Strass No. 1 " " $3KaO+9PbO+16SiO_3$; &c.

Although more probable suppositions may be formed with reference to the manner in which the silica is divided amongst the bases or the real constitution of the glass, and although the calculations above do not lead to any rational formulæ, yet the knowledge of the empirical formula for any species of glass as represented in the above examples, is, nevertheless, a very valuable guide in mixing the ingredients for its manufacture, and of great service in improving or correcting the prescribed rules.

Of the Material for Glass-Making.—In so extensive a branch of manufacture as that of glass, it is quite impossible to prepare or obtain the ingredients in a state of chemical purity previous to fusing them together; certain crude products of art and nature are, therefore, used, in which the ingredients are contained in some suitable form of combination, and it is left to the process of melting to eject the impurities in a more or less complete manner. In order to understand the nature of this process, and the recipes for mixing the ingredients of the different varieties of glass, it is necessary previously to become acquainted with the crude products which are used in the glass-house for affording silica and the bases.

Silicic Acid.—Silica is very abundant in nature, but is seldom sufficiently pure for the manufacture of the finest colorless glass. *Rock crystal* is frequently used for the production of *strass* and for those glasses which are employed as pigments by glass painters. Heated

to redness and thrown into water, the state of aggregation of this substance is so changed, that it can easily be reduced to powder. Massive *quartz* and *flint* are treated in the same manner; the water is thus expelled, and the organic matter which so often accompanies these minerals, is destroyed. Many varieties of quartz become yellow when heated to redness, and this indicates the presence of iron, which colors glass green; quartz is also contaminated with alumina, and this is objectionable when its quantity is so considerable as to interfere with the fusibility of the glass. *Sand*, however, is the most general and economical source of silica, and renders the process of grinding unnecessary. The great variations in the purity of this material render a careful selection necessary for the different kinds of glass. Sand contains either oxide of iron, clay, or lime, and generally all three substances are present, one of which preponderates and gives a character to the sand, which is also mixed with vegetable remains. The lime is, of course, harmless, as it is added from other sources. Clay can be removed nearly entirely, by washing and decantation, without any great expense, whenever its presence is objectionable, and this is always necessary with pit-sand, although not so essential with sea and river-sand. The oxide of iron is much more difficult of management; it can, indeed, be completely and easily removed by washing with muriatic acid, but the operation is attended with too great expense (at least, for the cheaper kinds of glass), and the glass-makers prefer seeking out sand free from iron. Thus, the vessels from Sydney and New Holland are freighted back with sand containing no iron, or take it as ballast to England, where the deposits of sand in Norfolk, and Alum Bay in the Isle of Wight, have proved insufficient for the demand.* In the greater number of glass-houses, the sand is heated to redness in a reverberatory furnace before being used, partly that the vegetable matters may be destroyed, and partly to render it finer and more easily acted upon. The saving effected in the fuel used in the melting furnace is so considerable, when the constituents of the mixture are in the most intimate state of division, that the consumption in the reverberatory furnace cannot for a moment come into comparison with it.

Potash and Soda.—The alkali used in the manufacture of ordinary colored glass (*e. g.* bottle-glass), is obtained, as far as the potash is concerned, from common *ashes*, and the soda from the *ashes of sea-plants*, or refuse soda (Barilla, Varec, compare vol. i. p. 285). Better kinds of glass are made with *crude potashes and soda-ash*, and the best from *purified* potashes and soda-ash. The use of the alkalimeter is very requisite in judging of the quality of so variable a substance as commercial alkali, although it is often neglected by practical men; it must also be borne in mind, in using soda-ash, that the soda possesses

* Excellent sand is also obtained for glass-making at Leighton-Buzzard and St. Helen's, in Lancashire. [The most perfect glass sand we have seen in the United States, is that found in the neighborhood of Pittsfield, Mass, brought to notice by Mr. Hodge, at the meeting of the Association of Geologists and Naturalists at Boston, Sept. 1847.—AM. ED.]

a higher saturating power than potash; 100 parts of pure carbonate of soda will perform the same function in a mixture of ingredients for glass, as 130 parts of carbonate of potash. It is obvious that the manufacture of glass would derive a great advantage if the soda could be supplied to the mass by the direct use of *chloride of sodium*. The cost of the manufacture of *soda* from common salt would thus be spared. But common salt is not a complete substitute for soda. Silica decomposes common salt very rapidly, in the presence of aqueous vapor, which is never absent in the flame of the furnace, into soda, with which it combines, and muriatic acid, which is evolved,

$$\begin{array}{rcc} & Cl_2 & Na \\ & H_2 & O \\ \hline \text{Muriatic acid} & Cl_2H_2 & \mid NaO\ \text{Soda}; \end{array}$$

but before the requisite temperature is attained at which this decomposition is effected, the greater part of the common salt is volatilized in the form of vapor, and this attacks the sides of the furnace in a very prejudicial manner; if potashes are present at the same time with the common salt in the mixture, these salts mutually decompose each other, with the formation of carbonate of soda, and chloride of potassium, which swims upon the surface of the glass in the form of sandiver, or glass gall (salts). According to Kirn, the amount of common salt, which in general does not exceed 5 or 6 per cent., may be raised to 13 per cent., when there is at least $\frac{4}{3}$rds as much lime in the mixture. The best result was obtained from a mixture of 2 parts common salt, 3 parts lime, 4 parts potash, and the necessary addition of 6 parts sand.* Instead of common salt, soap-boilers' waste† may be employed for the more common sorts of glass, which contain chlorides of potassium and sodium, carbonated, and some caustic alkali. Glauber's salt (sulphate of soda), which is obtained as a waste product in several manufactories, may also be used with advantage. As the sulphuric acid, however, is not very readily expelled, the action of the silicic acid is aided by converting the sulphuric acid into sulphurous acid in some appropriate manner, which then offers much less opposition. Carbon is best suited for this purpose, for:

$$\begin{array}{l} SO_3,NaO = NaO + SO_2 + O \text{ Glauber's salt} \\ \qquad\qquad\qquad\quad \text{and} + C \text{ carbon (charcoal) produce} \\ \hline \text{Sulphite of soda} = NaO,SO_2 + CO = \text{carbonic oxide.} \end{array}$$

Carbon colors glass intensely black or brown; any excess must consequently be carefully avoided. As a guide to the requisite quantity to be used, it must be observed that 100 parts of pure dry Glauber's salt require rather less than 9 parts of carbon for complete

* It is probable that this mixture would make equally good glass without the common salt.

† This term is applied to the mass obtained by the evaporation of the under lye in soap boiling, vol. i. p. 413.

decomposition. Trustworthy observations have proved that glass, prepared with Glauber's salt, always possesses a bluish tinge, which is not derived from impurity in the materials, and the color is therefore attributed to the formation of a minute quantity of ultramarine (composed of sulphur, soda, and alumina). In order to obviate this, the charcoal may be dispensed with, in which case the time of melting must be lengthened; or where lead-glass is in question, the mixture may be fused with sulphuret of lead, and the sulphuric acid of the Glauber's salt then parts with one-third of its oxygen to oxidize the sulphuret, and salts of sulphurous acid are produced. According to the observations of Kirn and others, it is preferable, (when not indispensable, in order to make sure of perfect vitrification,) where common salt and Glauber's salt are employed, to incorporate as much carbonated alkali with the mixture as would produce by itself a glass, although of difficult fusibility. When we remember that potashes are obtained chiefly from the ashes of wood, and necessitate a certain consumption of that substance, which quantity, although applied to useful purposes, must remain undiminished; and when it is further recollected that the consumption of wood in the German glass-houses has increased to an enormous extent, it will then be easily understood why the production of glass from chloride of sodium, and from the salts obtained from it which are not similarly connected with the consumption of wood, must be a matter of great importance with reference to political economy. The working of a single glass-furnace is calculated to consume, in Austria, 400 cwts. of potashes, which (supposing pine wood to contain 0.25 per cent. of ash, or 0.065 per cent. of potashes), would require the consumption of at least 615,400 cwts.=50,700 stacks* Hessian of pine wood, and 3,270 stacks Hessian yearly, in addition, as fuel. It is well known that when sand and common salt are brought together in a state of fusion, and aqueous vapor is passed over the fusing mass, the decomposition into muriatic acid and silicate of soda is effected without difficulty in a tolerably perfect manner. A trial of this process upon a large scale is well worthy the attention of manufacturers, for it is probable that the production of frit by this means—for which an ordinary reverberatory furnace might be used—and the subsequent employment of this frit as raw material, would be very much more profitable than the direct vitrification of the common salt. In this case, no chloride of sodium would be volatilized in the working, to the destruction of the sides of the furnace, and the glass-pots or crucibles. Sulphate of potash, when it can be procured, may be used in precisely the same manner, with the same precautions;—7 per cent. of the pure dry salt in charcoal is all that is here requisite. After what has been stated above, the application of lixiviated ashes (from the ash-tubs of the potash manufactories and soap-boilers); and of soap-boilers' waste, will be easily understood.

* Stack of wood=100 cubic feet, Hessian.

Lime.—Every kind of limestone is applicable to the manufacture of glass that is not too poor after being burnt and slaked. In the opposite case, it will contain too much magnesia, or alumina, either of which has a tendency to render the glass difficultly fusible. Limestone, containing proto-carbonate of iron, must be excluded from the mixture for making white glass. The use of unburnt limestone is not altogether inadmissible when it is in the state of a fine powder, for instance, as ground chalk; but burnt lime that has fallen to pieces in the air, is generally preferred, as it is then in a state of more minute division, and evolves less carbonic acid. When a glass mixture contains more lime than the silica which it comprises is capable of saturating, the excess attacks the material of the crucible, and extracts silica from it; the crucibles are thus quickly eaten away and rendered useless. It is consequently not advisable to employ more than 20 parts of lime for 100 parts of sand.

Lead.—Lead-glass is fused from a mixture containing *litharge* (PbO), or *minium* (red-lead, Pb_3O_4). The latter substance is preferred, on account of its finer state of division, its pulverulent form, and because it is decomposed in the glass-pot into ordinary protoxide of lead and oxygen, which latter oxidizes and removes many impurities (for instance, charcoal). Both oxides, as they are met with in commerce, contain oxides of copper and iron, which exert a very prejudicial influence, as lead-glass is much more susceptible of acquiring color from metallic oxides than ordinary glass. For this reason, minium is specially prepared, at least in England, for this particular purpose by red-lead makers. An excess of lead acts injuriously upon the melting vessels, and, besides inducing too great softness in the glass, gives it a yellow tinge. White lead, sulphuret of lead, and sulphate of lead, are seldom used; but the latter deserves a trial, as it is a cheap and very pure waste product of the calico print works, &c. The analysis quoted at pages 16 and 17 show that the varieties of lead-glass are not made with soda, but contain potash only. The bluish color imparted by soda to vessels made with lead-glass is the reason for its exclusion; these are necessarily made thick and massive, that they may not lose their shape in cooling, and consequently show the slightest tinge in a more marked manner.

Barytes.—Heavy spar (BaO,SO_3) is added to the constituents of common bottle-glass in some places, to render it more easy of fusion.

Vitrifiable Minerals.—Several, more or less, easily fusible compound silicates may be used as glass, or in its manufacture. Amongst these are *felspar*, *basalt*, *pumice-stone*, *clinkstone*, *lava*, *loam* (clay containing iron and lime), *marl* (clay containing lime), and others, most of which can only be used for the commonest kinds of glass. Some, like basalt, may be melted, without any additional matter, into highly colored glass; others are too difficult of fusion, like felspar, and must be previously mixed with lime and alkali. A glance at the following analyses will show at once the cause of these differences. The following substances have been found in—

	Pumice-stone from Lipari.	Basalt from Hasenberg.	Pitchstone from Meissen.	Common Felspar.	Glassy felspar from Pausilippo.	
Silica - - - - -	77.5	44.5	73.0	65.52	67.87	48.83
Potash - - -	3.0	2.6	1.75	14.73	6.68	
Soda - - - - -				trace	2.86	
Lime - - - - -		9.5	1.00	0.60	3.16	10.16
Magnesia - - -		2.2			1.40	13.61
Protoxide of iron - -						18.75
Alumina - - -	17.5	16.0	14.5	19.15	15.72	7.48
Peroxide of iron - -	1.7	20.0	1.0		2.41	
Fluorine - - -						0.41
Water - - - - -		2.0	8.5			0.50

An attempt has been made to manufacture glass from a species of granite, containing very little quartz, with an admixture of decomposed felspar, resembling kaolin, called *Cornish stone.* In like manner, the slag from smelting furnaces and other artificial products may be worked up into glass. In Valenciennes, bottles have been fabricated in several glass-houses by simply melting a bluish-brown marine mud from Dünkirchen, in which Pelouze and Baudrimont found—

Silica - - - - - -	43·75
Alumina - - - - - -	13·82
Carbonate of lime - - -	36·28
Peroxide of iron - - - -	0·36
Sulphate of soda and common salt -	2·75
Organic matter containing sulphur -	1·86
Loss (trace of iodine) - - -	1·18
	100·00

Discolorizing Matter.—White glass seldom or never turns out quite colorless by itself, even when proper proportions and the purest materials for the mixture have been employed in its production. There are always two antagonistic elements to contend with—*carbon*, or carbonaceous matters, and *iron*, which have to be overcome by the so-called discolorizing material. Peroxide of manganese, arsenic, and saltpetre, belong to this class of substances. In all cases the color is removed by oxidation.* If particles of carbon or soot from the flame happen to become surrounded and enclosed by the melted mass of glass, these are prevented burning, being excluded from the access of air. The consequence of this is a very intense brown or nearly black color, produced by the minute state of division, or, as it were, solution of the carbon in the glass. The addition of the discolorizing matter causes the formation of carbonic oxide, which is evolved with the color of the mass. The manner in which the iron becomes dis-

* It appears not altogether improbable that the reddish color produced by the higher oxides of manganese being the complementary color to the green tint produced by iron, may thus, in some cases, discolorize the glass.

colorized has already been noticed. An excess of manganese produces a heavy glass, containing oxide of manganese, which imparts a violet color to the mass at the bottom of the vessels. Saltpetre reacts before the glass enters into perfect fusion; arsenious acid, arsenic acid, and their salts, exert their action at a temperature above the fusing point, and are volatilized as arsenic or arsenious acid. *Smalt* is sometimes improperly included amongst the discolorizing matters; it is a blue glass (see below) which tends to mask the bad color of glass in a manner similar to that effected by blue starch upon yellow linen.

Broken Glass, or Cullet.—Fragments of old glass require particular notice as an indispensable addition to the ingredient of the crucible. The waste glass in the glass-house, and that collected in the neighborhood, is carefully sorted, cleaned, ground, and incorporated with the mixture for similar kinds of glass. These fragments exert a very beneficial action—in addition to the advantage derived from their being re-converted into glass vessels—by inciting fusion and by aiding the union of the bases with the silicic acid. Great care must, however, be taken that no broken glass of an inferior kind is mixed with the ingredients for finer glass. Even that which flows over the crucibles containing the purest glass, and mixes with the ashes of the hearth, must only be used for the inferior kinds.

Of the Fuel.—The furnaces employed in glass-houses are intended not only to combine chemically the ingredients of the glass mixture at a glowing heat, but also serve to retain the glass after fusion, in a proper state of fluidity for working. The mass of glass must consequently be accessible from without the furnace, both during the fusion, for the purpose of stirring the ingredients, and during the working. Again, the re-heating of the different vessels during working, which is always effected in the glass-furnace, requires imperatively a *flame fire*. This is, therefore, absolutely necessary on the one hand, whilst on the other it would not be practicable to heat the crucibles in immediate contact with the fuel, without exposing the glass to many chances of impurity. The fire space and the working space of the furnace must, therefore, necessarily be distinct, and at a distance from each other, and the latter must be heated by the flame alone, which is evolved from the fuel in the furnace: all glass-house furnaces belong, therefore, to the class of reverberatory furnaces. The high degree of heat required by the nature of the operation renders it obvious that every sort of fuel cannot be employed. That kind of fuel will naturally have the preference which produces the most intensely hot flame, and causes the least amount of damage to the glass and to the sides of the furnace from the deposition of ash. In Germany, *wood* is generally employed, and in some few places *peat;* in England and France, *coal.* The best air-dried wood would fall far short of producing the desired effect, in consequence of the water which it contains (from 15 to 20 per cent.). It has consequently been the practice from a very ancient period, to bake the air-dried wood in a particular kind of furnace until it begins to become brown, or until the whole of

its water has been volatilized. Even this precaution is not perfectly effectual unless soft woods are selected containing a large proportion of hydrogen; and these are cleft into very small billets. Finely cleft wood burns more rapidly and without smoke by coming into more extensive contact with air; it evolves its heat in less time, and although a greater amount of heat is not produced by its means, that heat which is produced is more intense. The peat used in the glass-house must be perfectly dry, and afford a small amount of ash only.*

The Furnaces.—The construction of the melting furnaces in a glass-house is attended with many difficulties, against which it is almost impossible to provide; and the wear and tear becomes a serious item to the manufacturer. The prevailing temperature of a glass furnace, 12000° C. (21632° Fah.), presents in itself a serious difficulty; but in cases where open pots are employed, this is materially increased by the volatility of the alkalies, which amounts to nearly 25 per cent. of the potash. The binary compound of silica and alumina becomes changed into a ternary one through the action of the alkali when clay is employed, and into a silicate of potash or soda where fire-stone is substituted; in each case a fusible compound results, which rapidly wastes away, and at last, both pots and furnaces become too much corroded for use. In ordinary cases, three years is the usual duration of these furnaces, except in flint-glass-houses, where they last longer, from the lower melting point of the materials and the peculiar shape of the pots.

The furnace is erected over a large flue, or *cave*, as it is technically termed, very strongly constructed, and 5 or 6 feet high. On each side of the grate-room, in which the flue terminates, a bank is raised, termed the siege, on which the pots are placed, so that the fire lies, as it were, below the bottom of the pots and in the centre of the furnace, but stretching through its whole length. The sides of the furnace are a little higher than the top of the pot, and the arch, or crown, is made as low as possible, to be consistent with durability. Openings are made in the sides of the furnace, opposite to each pot, and above all, a high cone is erected for the purpose of draught. In all kinds of glass, except flint, these openings are the only exit for the flames or heat into the cone, and the heat striking directly against the roof or arch of the furnace, is reverberated down upon the pots, finally escaping through these openings, or "working holes." This necessitates a great loss of heat, which is obviated in some degree in the flint-glass furnace, where the exit is by means of a flue or chimney, the entrance into which is low down in the side of the furnace, so

[* In several American glass-houses the only fuel employed is *rosin*. The absence of all earthy impurity, and the great volume of flame produced by this fuel, render it highly valuable, and the large quantities of late years derived from the manufacture of camphine, pine oil, and similar compounds, have made the article of easy attainment. Rosin free from dirt, is alone employed. It is generally pulverized, and supplied in very small quantities at a time, leaving no residuum and involving no danger of tarnishing the glass by dust or otherwise. At the moderate price of 60 or 80 cents per barrel of 250 pounds, rosin is found more economical and advantageous than any other species of fuel.—AM. ED.]

that the heat is compelled to encircle the whole pot before it can escape.

The sides of the furnace are constructed of bricks, formed in moulds made for the purpose. The best fire-clay, mixed with the remains of old pots coarsely ground, is the material employed for making these bricks; but it will be made to appear in our next group, that these clays would be much improved, for this and many other purposes, by the addition of some coarse sand or ground pure sandstones. The roof is generally made of sandstone alone, of a coarse grit, and very porous. No cement is employed in the arch; the expansion of the stone and the partial fusing of the interior surfaces afterwards, bind the whole sufficiently well together.

It is almost unnecessary to remark, that a long and cautious annealing is of the greatest importance in these furnaces, and that the foundations ought to be dry or well drained.

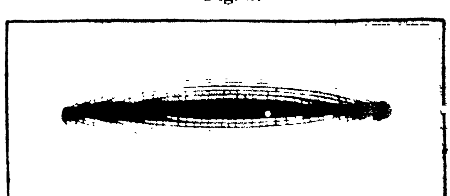
Some sketches which follow will give a better idea of the shapes of the furnaces employed in the different kinds of glass.

The Pots.—These crucibles, or pots, are next in importance to the furnaces, and every care is taken in their production. The best fire-clay, mixed with varying proportions of the remains of the old pots, is employed, and the *tempering*, or previous preparation of the mixture, requires great attention. A certain quantity of the ground materials, after being mixed with water, is stored away in large wooden bins or receptacles, and turned over from time to time, during which a workman treads it under his naked feet. This *kneading* of the clay renders it very uniform and free from particles of air. The following is the composition of some of these clays.

	Stourbridge.				Forges.	Leyval.	Nuzejoul.
Silica	68.05	61.15	64.10	63.70	65.00	52.00	47.20
Alumina	18.85	25.00	23.15	20.70	24.00	31.60	32.40
Ox. iron	5.10	1.10	1.85	4.00	traces	4.40	3.00
Lime	0.80	1.30	"	"	"	"	"
Magnesia	"	"	.95	"	"	"	"
Water	6.00	12.50	10.00	10.30	11.00	12.60	16.00
	98.80	99.95	100.05	98.70	100.00	100.60	98.60
	Richardson.				Berthier.		

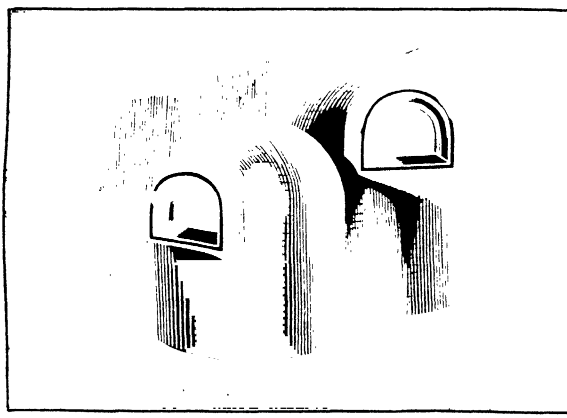
The clay thus prepared is rolled up into small pieces resembling that shown in Fig. 2 which the pot maker holds in his right hand, while he works it into a mass, slightly turned up on the edges, and spread out on a wooden board. This mass is the bottom of the pot, and the outer edges thus turned up, form the commencement of

Fig. 2.



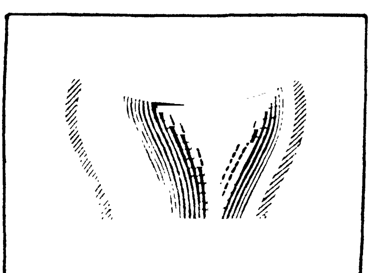
the sides or wall of the pot. The workman gradually works round and round the mass, adding piece after piece, his left hand retaining the shape of the sides by pressure from the inside, while each piece is being worked into the yet imperfect wall. The whole of the pot is, therefore, formed by the eye of the workman, occasionally assisted by measuring the diameter, taking care not to add more than 3 or 4 inches to the height of the sides each day. After each day's work, wet cloths are laid upon the unfinished sides, while a gentle heat is maintained in the room, the finished part gradually acquiring considerable consistency. It is of importance that the surface and upper part of the sides should not become too dry, as the successive additions would not then adhere, and the pot, after being placed in the furnace, would split off into rings, showing the points where the neglect of this precaution had taken place. When the pot has been finished, the sides are made smooth by means of small wooden scrapers. The following sketch (Fig. 3) shows the form in which flint-glass pots

Fig. 3.



are made; the only difference between these pots and those in use for other descriptions of glass, consisting in the absence of the hood or cover, while the upper part is slightly enlarged, something like the shape shown in Fig. 4.

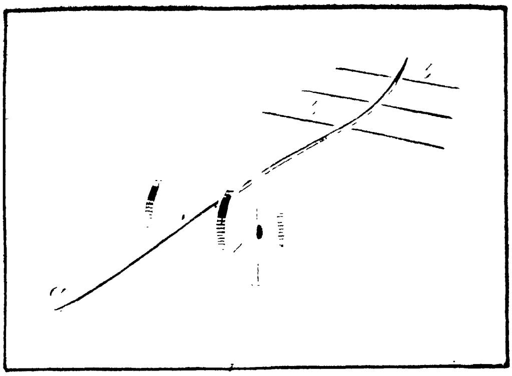
Fig. 4.



The annealing of these pots requires even more care than the furnace, and the older the pot, before it is heated to redness preparatory to being removed into the melting furnaces, so much the better. When brought to a red heat, it is carried from the annealing kiln to the furnace, on the end of a strong iron machine, of the form represented in

Fig. 5. The heated pot hangs on the end *a*, and the workmen sit upon the cross bars *b b* to counterbalance its weight, while others drive

Fig. 5.



the machine towards the open end of the furnace, in which the pot is gently laid on its side. By means of levers worked through different openings of the furnaces, the pot is gradually brought into its proper position, and is then "glazed," as it is technically termed, before being filled with materials; *i. e.*, some cullet, or old glass, is thrown into it, and spread over the sides in the melted state; this then penetrates, to the depth of a few lines, into the substance of the pot, and forms a hard difficultly fusible glass, which protects the pot from the further action of the materials.

Preparation of the Materials.—It has already been stated that a great saving of fuel and time is effected by intimately mixing the materials in the most minute state of division. Edgestones and sifting machinery are, therefore, essential in a glass-house. The materials are either mixed together in heaps, or, better, in the slowly revolving barrels similar to those employed in the powder-mills.

Until quite recently, the materials have always been mixed by the workmen, and the generally imperfect way in which this has been done, must have struck an attentive observer, as very prejudicial to the subsequent chemical changes that take place in their mutual reaction, before becoming a homogeneous fluid transparent body. In many chemical operations, the entire success depends upon the intimacy of the previous mechanical mixture of the ingredients, and we may point at least, to the importance of blending the charcoal and sulphate of soda in the case before us. Mr. Chance has proposed the following plan for remedying the objection. Fig. 6 is a vertical longitudinal section, and Fig. 7 a transverse section, of an apparatus for this purpose. The whole apparatus is made of wood, and consists of a chamber *a*, with an opening in the upper part *b*, for receiving the material, and another in the semi-circular bottom at *c*, through which they are again removed; *d* is a cylinder with numerous beaters fixed obliquely to it, and the whole is made to revolve by suitable

Fig. 6.

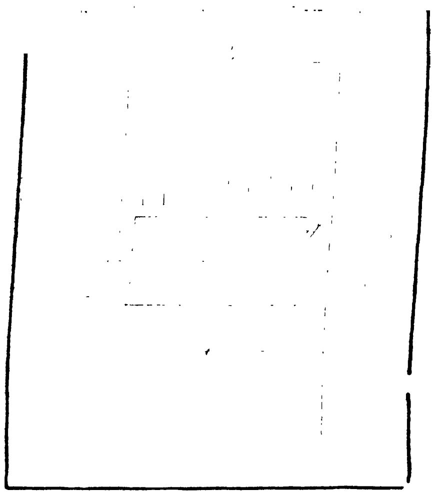
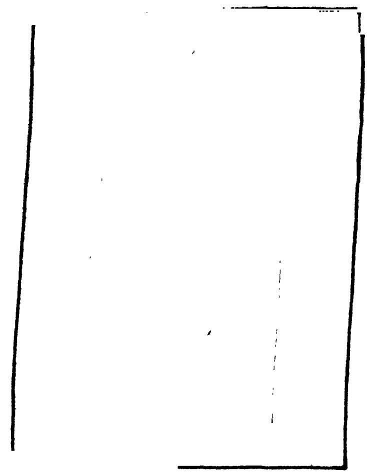


Fig. 7.



machinery and power. Mr. Charles Cowper finds that the mixture is best effected when the ingredients are placed in a revolving wooden barrel, constructed and set in motion upon the same plan as those used in the powder factories, as alluded to above, and described at vol. i. page 361.

Fritting.—In former times it was usual to heat the glass-mixture to such an extent, that an incipient fusion, or caking together, commenced, during which the silica began to act upon the bases, the carbonic acid was partially expelled, and a so-called *frit* was produced. As a high degree of heat is necessary for this useful though not absolutely necessary operation, it has recently, with the exception of certain cases, been discontinued. One great advantage of fritting consists in the partial union which it effects between the silicic acid and the bases, so that the latter are not volatilized in the furnace previous to the formation of the glass, and the pots and sides of the furnace are consequently not exposed to the injurious action of their vapors.*

Melting.—As soon as the pots have acquired a glowing heat in the tempering or warming furnace, usually called the pot-arch, they are transposed to the melting furnace; the apertures through which they are inserted are bricked up, and the fire is increased, during six or eight hours, until the melting is attained. The simply calcined or fritted mixture is then introduced, but not all at once. The mass of glass which a pot will hold, occupies before fusion, in the state of a mixture, just twice the space of the melted glass. Even supposing

* The substance called "*schmelz*" [enamel] in the Austrian and Bohemian glass-houses is a true *frit*, or an imperfectly melted mixture, composed of lixiviated ashes and sand. It is produced in the pots at the end of the campaign, when the furnace is no longer fit for regular work, and is quenched in water after being ladled from the pots, and used as an addition to the crude materials in the actual preparation of glass.

the crucibles capable of holding the whole of the mixture, it would not be advisable to add it all at once, as there would be danger of flowing over, and a solid nucleus would be formed, capable of resisting fusion for a long time. For this reason, one-third of the mixture is first introduced through the working holes, by means of shovels, and the other two-thirds are added successively, when the previous portion appears thoroughly melted. At this period, however, the perfect combination and solution of the ingredients are by no means attained, and the completion of the real melting process is only about to commence; the temperature is now increased by stoking the fire, until that degree of heat is attained which brings about complete fluidity, and allows full scope for the exertion of the chemical affinities without volatilizing too much alkali.

During the whole period of the melting or *found*, the stokers, or *teazers*, keep the furnace well supplied with fuel, so as to prevent any portion of the grates becoming uncovered, since a rush of cold air from below, would probably split some of the pots from top to bottom. During this operation, the founders* are engaged in observing the progress of the fusion, by taking from time to time proofs, or drops, from the pots, by means of a short rod, flattened at one end, and examining whether any undissolved grains of sand are perceptible on cooling, and whether the mass, which still contains a quantity of air-bubbles, appears uniform throughout. As long as carbonic acid is evolved with any degree of violence, or during the *boil*, the mass is agitated by the escape of the larger bubbles of gas in a manner very favorable to the progress of the operation; this motion answers the purpose of stirring, and mixes the compounds of variable degrees of fusibility and density, which are at first produced, with each other; at a later period, when the disengagement of gas ceases, the denser compounds are apt to settle down to the bottom of the pot, where the temperature is considerably lower (about one-fourth), and is consequently incapable of preventing the deposition by the production of ascending currents. This evil is moderated on the continent by stirring with the scooping ladle, or by thrusting a piece of white arsenic to the bottom of the pot, and thus causing a forcible expulsion of vapor from that part of the vessel. At the close of the melting process, the contents of the pot are not by any means pure, or equally mixed. The solid matter is indeed all dissolved, but the mass of glass is full of small bubbles of gas, presents a spongy rather than a dense appearance, and is not yet in a state fit for working. The surface is also covered by a layer of so-called *glass-gall*, or *sandiver*, a melted mixture of salts which have not been volatilized, nor combined with silica during the process of melting, and consisting chiefly of chloride of potassium (or sodium) and sulphates, which have escaped decomposition in consequence of imperfect vitrification.

The following has been found to be the composition of this saline matter (glass-gall, or sandiver), which is skimmed off the surface of

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* From the French *fondeur*.

the melting materials in glass-making, and is technically termed *salts:*

Constituents.	German plate-glass.	Crystal-glass.	Bottle-glass.
Water - -	1.65	.10	1.00
Sulphate of soda -	83.32	90.51	55.92
Sulphate of lime -	10.35	6.00	25.11
Chloride of sodium -	1.43	.04	.20
Carbonate of soda -	trace	"	"
Potash - -	"	"	trace
Insoluble matter -	3.25	3.35	17.77
	100.00	100.00	100.00

When this glass-gall occurs in large quantity, it is removed with ladles, and employed by saltpetre and alum manufacturers, or workers in bronze; in the finer varieties of glass, prepared from purer or purified materials, where, instead of crude potashes, ashes or soda, purified substances have been employed, either no glass-gall is produced, or that which appears is easily removed by volatilization.

Fining.—The last part of the process of glass-making is now arrived, which is termed *the fining*, and the object of this is the removal of the air-bubbles and impurities, such as undissolved grains of sand, &c., from the chemically finished glass in order to prepare it for working. This process is a simple separation of the heterogeneous substances by subsidence, in which the heavier particles settle down to the bottom, and the gas-bubbles rise and disperse on the surface of the melted mass. It is easily understood that this operation can only be successfully conducted when the glass is in the most fluid state, and opposes the separation of the foreign matters as little as possible; the heat of the furnace is consequently raised to the highest point, and this temperature is sustained until the mass appears fit for working. With reference to the temperature, this period of melting and fining is termed in Germany the *heiss-schüren* [hot stir]. During this time, which always comprises several hours, no chemical change occurs, with the exception of the volatilization of a little alkali; but the proofs drawn by the founder are much more uniform in texture and freer from bubbles, until, at length, the whole is recognized as thoroughly fined. The mass of glass which is now ready, in every sense of the word, can only be formed into vessels when it possesses a certain state of consistency, and this is entirely dependent upon a fixed temperature, which has been very much exceeded during this period. The working, consequently, does not immediately follow the fining process, but a period called the *kalt schüren* [cold stir] intervenes, during which the heat of the furnace is allowed to sink to that temperature at which the glass is in the best condition for working or blowing.

*Kalt-schüren.**—This period of the melting process begins with a

* This term, as well as *heiss-schüren*, used previously, is not capable of exact translation. The latter operation, *kalt-schüren*, is allied to what is sometimes called stopping, and consists in plastering up the bars of the furnace, after a large fire has been made

cessation of work on the part of the teazer, the fire is left to itself for half or three-quarters of an hour, and the interval is used for cleaning and clearing the grate and other parts in its vicinity. The teazing is then continued in such a manner as to keep the mass of glass uniformly at the temperature at which it is thickly fluid, and this temperature is secured by moderating the quantity of fuel, and employing denser varieties and such as are consumed with less flame. If, during the former period, pine wood had been used, beech wood would be the proper fuel for this part of the process. Observations with Wedgwood's Pyrometer have shown the temperature of the *kalt-schüren* to be 70°, that of the *heiss-schüren* 130°, which is equivalent to about 5055° C. for the former, and 9388° C. for the latter.

Faults in the Glass.—Glass without fault or blemish throughout is hardly attainable at any one melting, although the greater proportion of the manufactured articles may be faultless. The ordinary faults are attributable to a want of uniformity in the mass, and arise partly from imperfect fining, and partly from foreign matters falling into the melting glass. Undissolved sand forms white grains, and particles of undissolved saline matter appear in the flocculent form. The appearance of opacity in certain parts is more generally diffused, and is produced by a very fine precipitate in lesser or greater quantity. This often arises from the presence of insoluble matters, as bone-earth, oxide of tin (compare bone-glass), or from certain circumstances, the nature of which has not been minutely investigated. Air-bubbles frequently remain, and generally exist in great number when the fining process has been obstructed by too great difficulty of fusion in the glass, and are technically termed *seed*, *blibe*, or *blister*. *Threads* or *strings* are produced when, during blowing, cold particles of glass drop into the melted mass, and extend as projections from the blown vessels, being no longer in a state of complete fusion.

Waves and striæ are common imperfections, and are very objectionable in glass for optical purposes, and in window-glass; they are caused by certain portions of the glass, which are not different in transparency or color, refracting light more powerfully than others; when portions of glass of different degrees of density cross each other in opposite directions, the images of objects seen through the glass appear out of place and distorted, and the fault is very objectionable. A similar, but much more serious inconvenience, which is frequently a source of color in the glass, arises from the action of the alkaline vapors upon the constituents of the sides of the furnace, particularly when common salt or sulphate of soda is used in the manufacture. In this case, that portion of the arch situated immediately above the glass-pot being most exposed to the vapors, its silica combines with the alkali and forms, with it and with the iron and alumina of the clay, a green and very difficultly fusible glass, which creeps down

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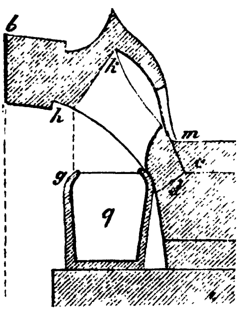
and allowed to burn clear, or covering the fire with a quantity of loam and shutting the cave doors. The heat is then gradually reduced to the proper temperature for working. The great thickness of the walls of the furnace, and the slow combustion of the fuel, keep the furnace hot enough during the period in which the glass is blown.

the curved roof and drops from the first small inequality on the surface, or from that part where the surface is more horizontal, in thick drops into the pot. As these drops are very different from the mass of the glass, both in composition and fusibility, they sink down to the bottom instead of melting, and leave a fibrous tail, which coils about in the substance of the glass-vessels.

Fig. 8.



Knots of this kind are produced, though less frequently, by the action of the glass upon the mass composing the crucible. The drops of aluminous glass are prevented falling into the crucible, according to Kirn, by constructing the pots and the arch of the furnace in the manner represented at Fig. 8. The segment of the wall of the furnace *a b c d*, which comprises the working-hole, is so large, that drops falling in a perpendicular manner from the corner *h* (in the direction of *h g* therefore), can only reach the inflected margin of the pot *q*. A second, less solid arch, *i k m*, reduces the size of the working-hole to the proper dimensions.*

OF HOHL-GLASS.

Varieties of glass, differing in composition and of very variable quality, are comprised under this term in consequence of the similarity which exists in the mechanical process of working them, and in the management of the melting operation.

All kinds of hollow articles, as bottles, drinking vessels, preserving glasses, chimney glasses for lamps, goblets, tubes and chemical vessels in general, from the finest Bohemian glass for cutting and grinding, to the ordinary green bottle-glass are included under this head.†

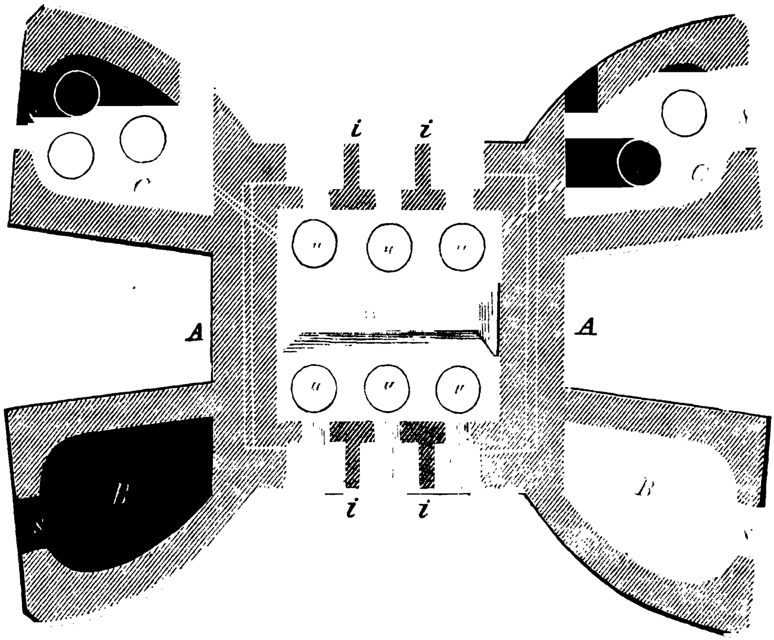
Hohl-glass Furnace.—The arrangement of an ordinary hohl-glass furnace is shown in Figs. 9, 10, 11, and 12. The Figs. represent a four-sided furnace, intended for six glass pots, and constructed in a very appropriate manner; it can be used for all kinds of glass belonging to this class. Fig. 9 represents a horizontal section at the height of the sieges or seats. Fig. 10 a perpendicular section through the teazing arch; Fig. 11 is also a perpendicular section through the sieges, and Fig. 12 is a front view with a section of the fritting kiln.

There are four side kilns connected with the main furnace *A*, in the shape of four wings, viz., two cooling or annealing furnaces *B B*, and two fritting kilns *C C*. Above the foundation, in which the drains

* Another plan is to make the working-hole in the perpendicular wall of the furnace and to spring the arch of such a form that the angle of the part over the pot may be sufficient to cause the tears to flow down the arch instead of dropping into the pot.

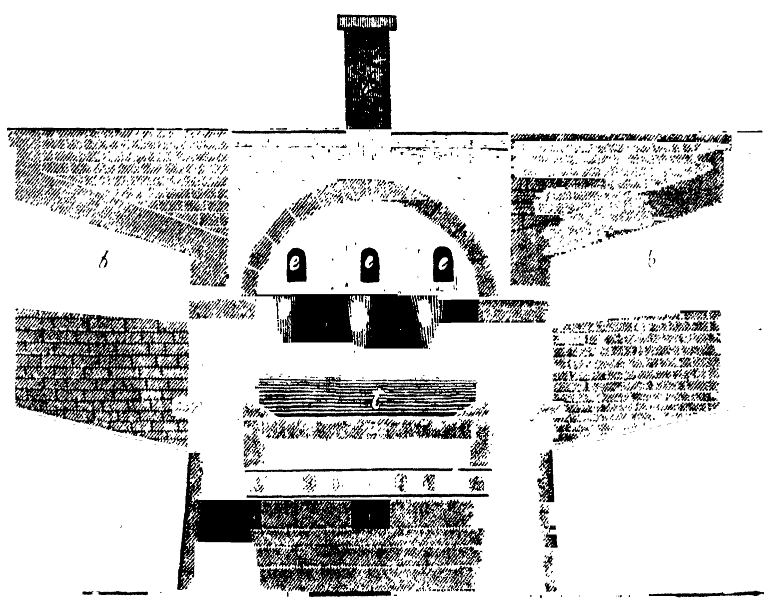
† In those cases where these glasses contain a certain amount of lead—which is not generally amongst their constituents—the lead is only of secondary importance, and intended to render them more easy of fusion.

Fig. 9.



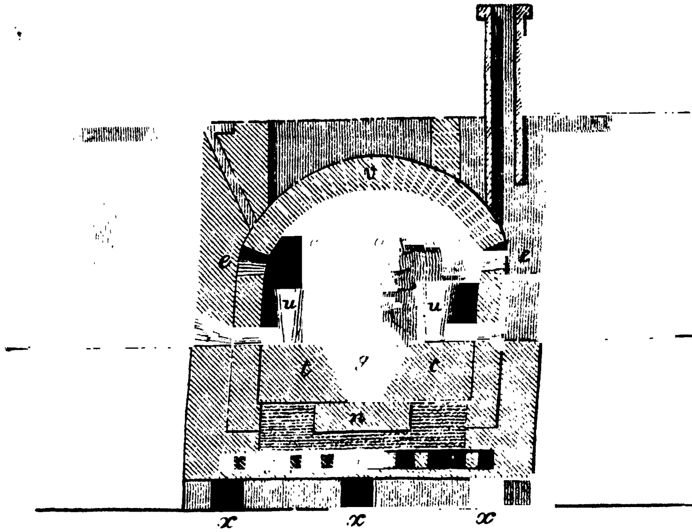
x x x are excavated, the sole-stone *w* is placed which forms the bottom of the fire room. The two fire-places and grates *m m* are situated

Fig. 10.



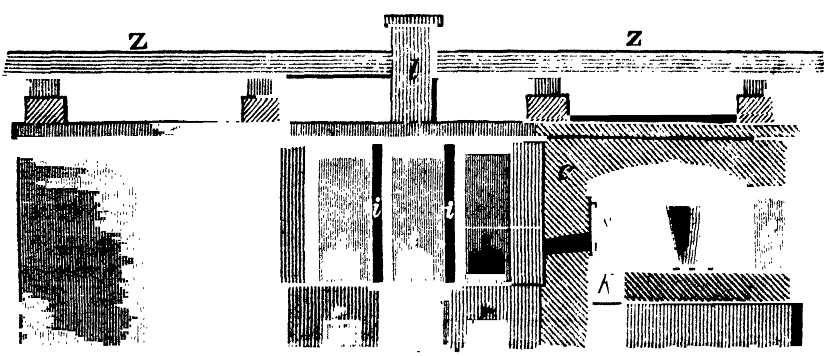
above the ash-pits *y*, and are exactly opposite to each other; they are supplied with fuel from the arches *b b* and *d d*, whilst the flames from the two extremities meet in the fire room *g*, Fig. 11, and enter together the space *a a* occupied by the pots *u u u u*, and—reverberating from the four-sided arch—escape at last through the flues *c c*,

Fig. 11.



eight inches in width, into the side ovens, of which two *c c* can be heated by separate fires *k k*; the damper *S'*, Fig. 12, shuts off the flame from the furnace *A*, when required. The uprights *i i i i* separate the working spaces of the glass-blowers, who obtain access to the glass in the pots through the working-holes *e e e*. Immediately below these are the openings *r r r*, which can be opened for removing the pots, when broken or worn out, from the sieges, to which they often adhere. In order to retain the heat in the furnace, the working-holes

Fig. 12.



are made as narrow as possible, and consequently much smaller than the pots; when it is necessary to change the latter, they are removed through the side arches, of which there are two in every furnace, and these are kept constantly bricked up, except when actually in use. Chimneys *l* are sometimes erected over one or more of the working-holes to carry off the heat and the vapors from the pots; these, however, are not essential, and are not often used. The side kilns are accessible by the doors *S S S.* Wood is placed on the scaffolding *z z* to dry. The cupola or arch *v* is walled over with ordinary bricks, and the corners are filled with sand and earth.

The round melting furnaces, although very commonly used, are not so commodious as those of quadrangular form under the same circumstances. If, for instance, six pots are to be set, each of which is 24 inches wide, then the arch of a round furnace, at the height of the sieges, must be at least 96 inches in diameter, and a cross section will consequently comprise 7238 square inches; in the quadrangular furnace, on the contrary, the three pots arranged on either side occupy respectively 72 inches, and the spaces between them 6 inches, which amounts to 78 inches lengthways in all, and, with a breadth of 72 inches, gives a transverse section of 5616 square inches. In a round furnace, therefore, the same height in the arch, the space to be heated will be as much greater as 7238 : 5616=9 : 7, or $\frac{2}{9}$ths greater, and the amount of glass that can be worked in it is not large in proportion. The quadrangular furnaces also afford better opportunities of connection with the side ovens, but do not allow so much space for the operations of the workmen as the round.*

BOTTLE-GLASS.

Composition.—In choosing ingredients for this kind of glass, economy is the chief object; color and appearance are here of no moment, and the discolorizing materials are consequently altogether left out of the mixture. Although local causes and other adventitious circumstances have given rise to such great diversity in recipes for glass mixtures, that nothing positive can be stated upon the subject, yet the following examples will help to illustrate both the exceptions and the rule followed in these cases; they are all calculated for 100 lbs. of sand:

FOR CHAMPAGNE BOTTLES ACCORDING TO JAHKEL.	ORDINARY GREEN BOTTLE GLASS.	DARK GREEN BOTTLE-GLASS.
200 lbs. felspar	72 lbs. of lime	20 lbs. dry Glauber's salt
20 " lime	280—278 " lixiviated wood ashes.	18 " soap-boilers' flux
15 " common salt		1 " Scheffel (pruss.) lixiviated ash
125 " iron slag.		39 " glass from the hearth
		179 " green cullet or broken glass
		45 " basalt.

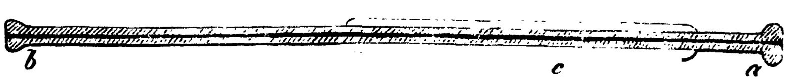
* For an elaborate discussion on the construction of glass-furnaces, including the above points, see an admirable paper by Kirn, in Erdmann's Journal, vol. xi. p. 34.

ORDINARY FRENCH BOTTLE GLASS.		ENGLISH BOTTLE-GLASS.	
30 — 40 lbs.	varec	100 lbs.	lixiviated ashes
160 — 170 "	lixiviated ashes	40 — 90 "	kelp
30 — 40 "	fresh ashes	30 — 40 "	wood-ashes
80 — 100 "	clay containing iron	80 — 100 "	clay
100 "	broken glass.	100 "	cullet.

It is obvious that all these mixtures contain potash, soda, lime (also magnesia), alumina, and iron as bases in different forms of chemical combination. The common yellow sand which is used without previous purification, adds materially to the amount of iron in the glass. The mixtures for bottle-glass and finer kinds of hohl-glass, are either melted in the same furnace, that the refuse from the latter which flows into the *cave* or main flue may be more profitably used up, and those parts of the furnace may be turned to account in which the finer kinds of glass would be endangered by the current of particles of ash; or separate furnaces are reserved for bottle-glass alone. In the latter case, no true fining is carried on, but the blowing operations begin as soon as vitrification is accomplished, and the mass appears tolerably free from foreign matters so as to admit of being cooled to the proper temperature.

Mechanical Operations.—The manufacture of bottles affords a good instance of the dexterous manipulations which are practised in blowing glass. The mode of working carried on in Spessart, is the most easily understood on account of its simplicity. The most important instrument is the "*pipe*" (Fig. 13). This is a tube composed of

Fig. 13.



wrought iron, 4 to 5 feet long, 1 inch thick, and about $\frac{1}{4}$ inch in the bore, having a knob at each end, the one of which *a* serves as a mouthpiece, whilst to the other *b* the melted glass is attached. To protect the workmen from the heat of the metal, a wooden handle *c* about a foot in length, surrounds the upper part. As soon as the working-holes are opened, and the surface of the glass is cleared from sandiver or glass-gall, the workman attaches as much melted glass to the end of the pipe *b* as he considers necessary for the production of a single bottle; his eye and hand are here unfailing guides as to the requisite quantity. By dipping the previously warmed pipe into the pot, a little glass remains attached to *b*; after turning this in the air before the hole, until it is cooled, and blowing slightly into it to render it hollow, a fresh layer of glass may be attached to it in the pot; to this, a third is added in the same manner until the ball at the end of the pipe has accumulated to a sufficient size. That this ball may become uniformly tractable in the subsequent forming, it is held by the workman in the flame of the furnace through the working hole, it is then brought into one of the round concavities of the *marver*,* Fig. 14, a moist

* Constructed at different times from a stone, marble or cast-iron plate.

board, where the ball gradually assumes the form of a thick hollow globe, or rather pear-shaped vessel, Fig. 15. It acquires this shape by the constant rotary motion given by the workman to the pipe whilst the cooling and stiffening of the mass are rendered uniform by the marver, and it is prevented shrinking together by constantly blowing into the pipe with very little force. The mass of metal* must be equably distributed round the axis of the pipe, and advanced in front of its mouth, being connected with it only by a short neck. Towards the front part where the subsequent widening occurs, and the mass is blown out, it is thickest, the portion nearest the pipe is less massive.

Fig. 14.

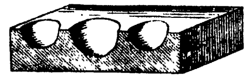
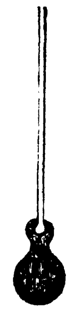
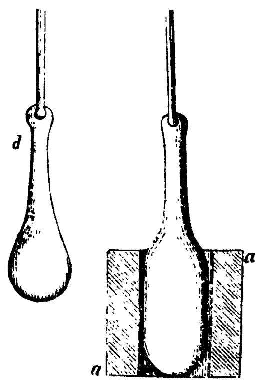


Fig. 15.



Thus far advanced, the glass has again become cool, and is re-warmed by insertion into the working-hole, in such a manner that the front part receives the chief portion of the heat, and becomes the softer. The pear-shaped vessel is now lengthened by the blower, and its form is approached to that of a bottle by a threefold operation: by blowing into the tube with greater force, by *swinging* (backwards and forwards in the manner of a pendulum) and by a simultaneous constant rotary motion of the pipe round its axis. The globular form which the glass tends to assume under the influence of the blowing, is converted into a long thin egg shape by the swinging motion (Fig. 16); and so much the more as the lower temperature at *d* is less favorable to the formation of a globe than to the lengthening of the neck. The rotation round the axis of the pipe is an essential part of every operation in glass-blowing. The glowing mass of glass creates a powerful current of air in an upward direction, and the lower portion becomes cooled in consequence much more than the upper. This naturally creates an inequality in the resistance offered to the blowing, and the upper portion would be more expanded than the lower if the cooling influence were not allowed to act upon all parts of the surface alike by the revolving motion of the pipe, and this is particularly the case when the pipe has to be held in a horizontal position. The mould *a* (a simple cylindrical hollow block of wood or iron) is placed at the side of the workman who is blowing the pear-shaped vessel; into this he inserts the vessel as soon as it has acquired the proper thickness, in the manner represented at Fig. 17, and by blowing forcibly into the tube, he presses the glass firmly against the sides of the mould, whilst, by a kind of

Fig. 16. Fig. 17.



* Metal is the technical term applied to glass during working.

jerking motion, the neck is drawn out to the proper length. The unfinished bottle, which as yet has no bottom or mouth, is again warmed in the working-hole in such a manner that the lower part only is heated, whilst the other parts remain comparatively cool. In the meantime another workman or a boy has attached a small quantity of glass to another pipe or rod of iron, called the *punty* or *pontil*, which is also kept hot in the working-hole. Both workmen now stand opposite to each other; and whilst the pipes are kept constantly turning, the punty is forcibly pressed against the middle of the lower part of the bottle which is thus forced inwards, and an even edge is produced, upon which the bottle may stand steadily. The bottle remains for some moments between the two instruments, Fig. 18, until, by the application of cold iron or a drop of water, the neck can be separated from the pipe.* The bottle is now supported by the punty, as shown at *a* (Fig. 18), so that the neck can be warmed, and the sharp edges melted round without softening the other parts. A rotating motion

Fig. 18.

is now given to the red-hot neck, the pipe being rolled backwards and forwards upon the knees of the workman, as shown in Fig. 19. The

Fig. 19.

bottle then revolves upon its axis as if it were placed in a lathe, and it is only necessary to press the shears, or an iron instrument like

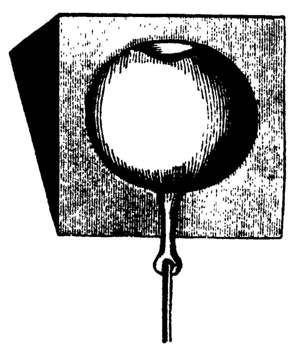
* This sudden separation is an operation of constant recurrence in the glass-house, and is effected by a sudden change of temperature produced at the point of separation in the hardened glass, either by the cold application of a drop of water, or by the powerful heat of a red-hot iron or thread of liquid glass from the pot. The point of separation must often be re-heated in order to fly on the application of cold water.

a turning chisel, against the mouth to widen or reduce it to any required dimensions; the rim for strengthening the neck is formed from a drop of glass taken from the pot by the edge of the flask and wrapped round the mouth in the form of a thick thread. The bottle, which is now finished (Fig. 20), is immediately carried by the punty-rod to the annealing-oven by a boy, pushed into its proper place, and the punty-rod is lastly detached from the bottom of the bottle by a sudden sharp jerk. The place where the punty was attached is perceptible in every bottle blown in this manner by the sharp edges where the fracture occurred.

Fig. 20.

Large round bottles are blown without the use of a mould, and when of very large size, like the carboys for sulphuric acid, the aid of steam is called in, by spurting a mouthful of water into the interior, and holding the mouth of the pipe with the thumb. Bottles in the shape of a flattened globe are also made without any mould by simple blowing. The preparation of the mass of glass, the formation of the concave bottom and of the neck, is in this case effected in precisely the same manner as above; the swinging motion, however, must not be continued for such a length of time, as the bottles required are shorter. In blowing the belly of the bottle, the workman stands in front of a slanting board (Fig. 21), and presses the globe, as it is gradually formed by slow blowing, against the board at every half revolution of the pipe, the flat surfaces on opposite sides are thus produced.

Fig. 21.



Where bottles are necessarily sold with a legal stamp upon them, and when their capacity must be suited to the standard measures of the country, the fulfilment of these conditions presupposes an extraordinary degree of dexterity, and correctness of eye in the blower. Attempts have consequently been made by many inventors to furnish the bottle-maker with a mould of such construction as would enable him to secure the formation of a bottle, perfect both as regards form and capacity, at one single operation, without reliance upon his own correctness of sight. The use of moulds of this description, like that of Rickets, which is easily managed, affords a great saving of time and renders the repeated heating of the bottles unnecessary.

The mould consists of a body which forms the belly of the bottle and of four other parts, a fixed bottom-piece with a movable piston for forming the concavity, and two movable pieces for the neck. Two treadles set these different parts in motion. As soon as the workman has introduced the hollow lengthened globe into the belly of the mould, by pressing with his foot upon the first treadle, he brings up the neck-

piece, then forces the glass into contact with all parts of the mould by a powerful blast, and finishes the bottle by working the second treadle, which forces the pestle against the bottom. On the removal of the pipe, the rim of the neck is all that remains to be perfected.

Champagne bottles require to be made more than usually strong, in consequence of the pressure exerted by the carbonic acid enclosed within them, and they are particularly liable to fracture during the bottle-fermentation of the wine. So great is the loss occasioned by the fracture of champagne bottles, that it is even worth while to test each bottle singly before using it. A special machine is employed for this purpose (those of Collardon and Desbordes are the best), by means of which water is forcibly pumped into the bottles until the stand of the manometer shows them to have withstood a sufficient degree of pressure. Although every bottle, when quite filled with water and containing no air, will burst in the belly from a slight blow on the cork in consequence of the sudden force being communicated from the liquid to the sides, yet champagne bottles will often withstand a pressure of 40 atmospheres, and upwards (=600 lbs. on the square inch).

WHITE HOHL-GLASS.

Composition.—The following instances of composition may serve as general standards:

FOR APOTHECARIES' PHIALS.	SEMI WHITE.	CLEAR WHITE.
100 lbs. of white sand	100 lbs. sand	100 lbs. sand
30 — 35 " potashes (impure)	100 " crude soda	65 " calcined potashes
17 "	conts lime	6 " fallen lime
110 — 120 " ashes	100 " cullet	100 " white cullet
¼ — ½ " perox. manganese (cullet).	½ — 1 " manganese.	½ " manganese.

BOHEMIAN CRYSTAL FOR GRINDING.		WHITE GLASS FOR CHEMICAL PURPOSES (*Solinlass*).
100 lbs. white sand	100 lbs. sand	100 lbs. white sand
0 — 60 " purified potashes	30 " potashes	41 4 " potashes
8 " chalk	18 " lime	17.5 " lime.
40 " broken glass	discolorizing matters.	
¾ " manganese.		

These examples will suffice to show the general character of white hohl-glass, viz., that it is composed of purer materials, which are as free from iron and alumina as possible, with the use of discolorizing matters. A complete process of fining is always carried out, whatever may be the differences in the composition, rendered necessary by the various applications of the substance. Glass for chemical purposes must combine transparency and perfect absence of color, with the property of being difficultly decomposed, although this is of minor importance for other applications. A few additional instances will prove that the working operations are essentially the same as those already described, and will show some of the expedients that are had recourse to under particular circumstances.

Mechanical Operations.—One of the simplest cases is exhibited in the blowing of a flask, Fig. 22. According as the blast is kept up with more or less force during the swinging operation, the neck will be more extended or more cylindrical. Before blowing out the globe, the glass below is re-heated, but not that above, which is to form the neck; if the revolving motion is stopped, the pipe having a downward direction, before the globe is completely formed, and the pipe is inverted into the position represented in Fig. 23, the belly sinks below the axis of the neck of the flask, and a retort is formed; no indentation occurs, as the constant blast keeps up the pressure of air in the interior.

Fig 22.

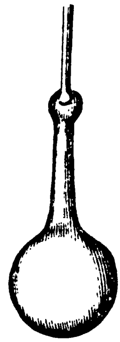


Fig. 23.

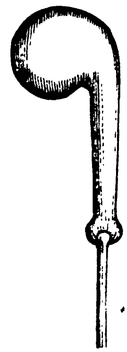
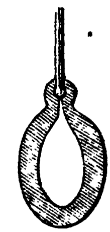


Fig. 24.



When a hollow lump of glass, for instance a globe, is drawn out whilst hot, the cavity in the interior is always preserved, and even when the drawing process is carried to its utmost limits the thread of glass appears under the microscope in the form of the finest capillary tube. Upon this depends the process of tube-drawing in the glass-houses, for which operation two workmen are required. Whilst one man collects the necessary quantity of glass on his pipe, and blows this out to a very massive globe, preserving a uniform thickness of the sides as much as possible, Fig. 24, the other attaches a drop of glass to a punty-rod, and warms it in the fire by the side of the globe. Both instruments are then removed from the fire at once, and the punty-rod is pushed forcibly against the globe in such a manner as to form exactly a straight line with the pipe, as represented in Fig. 25; this being accomplished, one of the workmen retires backwards as quickly as possible to the distance of 50, 60, or 100 feet. In this operation the globe shrinks at first, as is represented at *a* in Fig. 26, and forms the commencement of the tube, which soon cools and does not diminish in thickness, whilst the mass of glass is spun out by the constant drawing from the warm end at *b b*. Constant rotation of the pipe and punty-rod is here as necessary as in all the other operations in glass-blowing, or the part of the tube nearest the ground would cool quickest, and the tube thus assume an irregular form. This, however, does not prevent the tube, in consequence of its great length, from sinking in the middle like a stretched

Fig. 25.

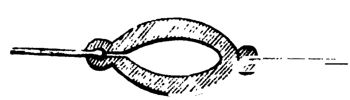
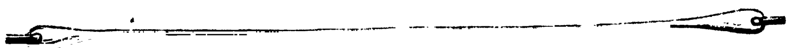


Fig. 26.

rope, and it becomes, consequently, thicker at the two ends, as is represented in Fig. 27. The curve in the tube is, however, remedied by placing it on the ground before it has become perfectly set, it then

Fig. 27.



straightens, and is cut into lengths of 4 or 6 feet each, by taking hold of it with a pair of cold tongs. Tubes cool very uniformly, in consequence of their small amount of metal, and they are, therefore, not placed in the annealing oven. Lastly, the bore of the tube is dependent upon the length to which a given mass of glass is stretched, or the length being the same, upon the mass of glass. The stoutness of the tube is, however, determined by the thickness of the sides of the original globe, as the relation between the thickness of the sides and the bore is not altered by drawing. Wide, thin tubes (such as are used for spindles, &c.) must, therefore, be drawn out of a large thin globe, and *vice versâ* : it is necessary, however, whilst the tubes are drawing to blow into them, that the sides may not sink in.*

Crown Glass.—The purest and most beautiful glass is the white "*crown glass*" manufactured in the Bohemian glass-houses for grinding and polishing. Intended for articles of luxury and art more than for the supply of the ordinary wants of life, the purity and absence of color in the mass are naturally heightened by the grinding and polishing, and are combined with an elegance of form which would be thrown away upon a less pure material. The most careful selection of materials, both for the mixture and the pots, and the smallest possible quantity of base—which always imparts more or less color—are the only means of securing a complete absence of color, and a protracted and assiduous process of fining is the only safeguard for a sufficient state of purity. These conditions are more difficult to comply with in this case, because the grinding demands a greater thickness of metal. The expense, on the other hand, is here no object. Glass, for the purposes of the grinder, is better prepared by the use of proper moulds than by simple blowing, partly because the forms are frequently not so simple as to admit of their being made by hand; and partly because the various grooves and projections upon the surface can be roughly given by means of a mould without adding to the difficulty of blowing, and time and trouble are thus saved in the laborious operation of grinding. The moulds, and the mode of using them, resemble, in every respect, those which will be described under flint-glass or crystal.

OF WINDOW-GLASS.

Properties.—Although window-panes may be made from any kind of hohl-glass that is not too much colored, just as many articles of hohl-

* For further particulars upon glass-pipes, &c., see Flint-glass.

glass are actually prepared from window-glass, *i. e.* watch and clock glasses; yet, with reference to the object in view, a very marked difference is made in the mixture of ingredients. The amount of lime in the mixture must not be too small, that the panes may not be subject to become opaque when exposed to the atmosphere (p. 18), whilst, on the other hand, any composition that has a tendency to devitrification would be a serious evil, as the glass has to be successively heated a great many times before it acquires the proper form for window-panes. Perfect absence of color is only requisite in very superior and large panes, which must also be of greater thickness; a straw-colored or greenish hue being hardly perceptible in the thin panes. If several ordinary panes are placed one upon the other, the bluish-green tint is frequently very palpable, particularly at the edges. The following are instances of the composition for window-glass.

GREEN.	SEMI-WHITE.	PERFECTLY WHITE.
100 lbs. sand	100 lbs. sand	100 lbs. sand
20 — 25 " potashes	50 " purified potashes	52½ " potashes (purified)
8 " panstone	20 " chalk	14½ " chalk
180 " wood ashes	1½ " saltpetre	⅗ " perox. manganese
120 — 150 " broken glass	1½ " arsenic	125 " broken glass
2 " wood-charcoal.	1/12 " perox. mang.	

RUSSIAN	OR:	OR:
100 lbs. sand (washed)	100 lbs. sand	100 lbs. quartz sand
50 " fir ashes	30 " calcined potashes	30 — 35 " dry purified soda
150 " willow ashes	15 " common salt	35 " chalk
40 " straw ashes	22 " lime	180 " broken glass
		¼ " perox. manganese
		¼ " arsenic.

The following mixtures are in use in some English manufactories.

CROWN-GLASS.

	lbs.	lbs.	cwt.
Sand - - -	560	448	16
Chalk* - -	154	146	5
Carbonate of Soda -	119	168	5
Sulphate of Soda -	63	17	1¼
Arsenic - -	2	2	0
Cullet - -	448	448	16

GERMAN SHEET.

	lbs.
Carbonate of Soda - - - -	34
Sulphate of Soda - - - -	30½
Chalk* - - - - -	47
Sand - - - - -	100

From the analysis quoted at page 24, it appears that in window-glass, for every equivalent of potash, there is from ½, ⅔ to 1 equiv. of lime, whilst in hohl-glass the lime is in the proportion of 3 equivs.

Production of Window-Glass.—The mechanical production of

Quick-lime, which has fallen by the action of the air, is now preferred.

window-glass is effected with the pipe, either by blowing a hollow cylinder, which is cut open and flattened out, in a special operation (*sheet or broad-glass*), or by distending with the aid of centrifugal force, a more globular-shaped vessel attached directly to the pipe (*crown-glass*).

SHEET-GLASS.

Cylinder Blowing.—The operation of blowing cylinders commences as usual with the collection of a sufficient quantity of metal from the pot at the end of the pipe. A massive glass ball is thus attached round the knob of the pipe which must be pushed forward with a *flatting-iron* until an annular groove is produced as at *a*. (Fig. 28.) This operation (*Schränken*) completed, the blower rounds the ball on the marver, and distends it slightly by blowing. It then assumes the form represented in Fig. 28, from which it will be seen that the mass of glass is thickest in front, as from that part it has to be distended and lengthened into a cylinder. In the subsequent operations, it first assumes the width of the future cylinder and then the length. With this object in view, the workman, after having re-warmed the ball of glass, holds it perpendicularly above his head, and blows into it. The heavy bottom yielding with less ease to the blast, admits of the distension of the mass in width, and a flattened bottle is formed (Fig. 29). As soon as the proper width is attained, the pipe is quickly inverted, so that the ball is undermost, and an incessant swinging motion is now kept up with a constant blast. Further distension is thus effected, but from the bottom only, as the thinner sides have by this time cooled, and in consequence of the swinging motion in the direction of the length, so that the bottle acquires the form represented in Fig 30, by the time that the glass has so far cooled as to be no longer expansible. If the swinging were omitted, the bottle would be distended in all directions,

Fig. 28.

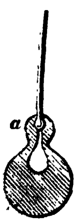


Fig. 29.

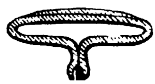


Fig. 30.

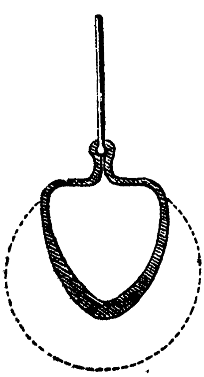


Fig. 31.

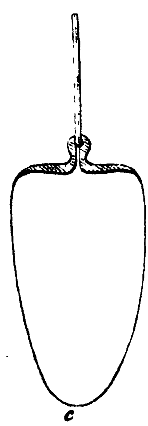
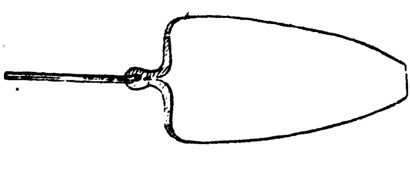
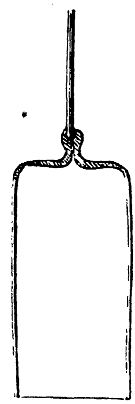


Fig. 32.



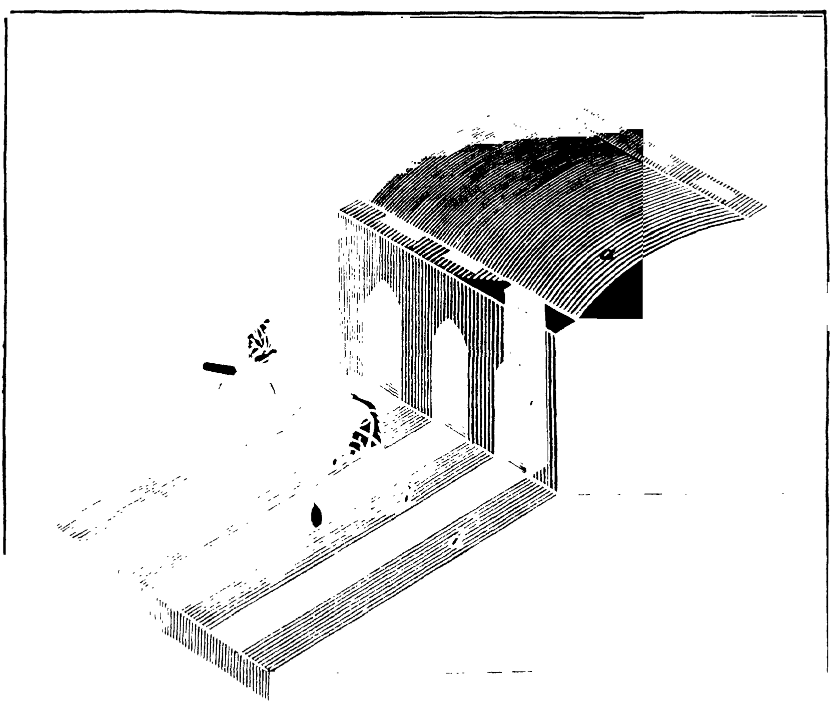
and present the form indicated by the dotted line. By repeated warming, swinging, and blowing, the form (Fig. 31) is gradually produced, which is then the proper length of the cylinder. It is then conical, and terminated by a semicircle, in the middle of which, at *c*, is the thinnest part of the vessel. When the workman blows air into the pipe, and closes the aperture with his thumb before withdrawing the pipe from his mouth, the air expands and exerts great tension upon the sides of the cylinder; if the weakest part, at *c*, is now held in the flame, it will be blown out and burst.* The cylinder having thus been *opened* as represented in Fig. 32, the next object is to extend the somewhat uneven and thick margin of the aperture, and reduce it to the proper dimensions, whilst at the same time the other parts are straightened and acquire a uniform diameter, as is shown in Fig. 33. Prominent portions which may sometimes project, are cut away with the scissors.

Fig. 33.



In order to convey a better idea of the swinging mo-

Fig. 34.



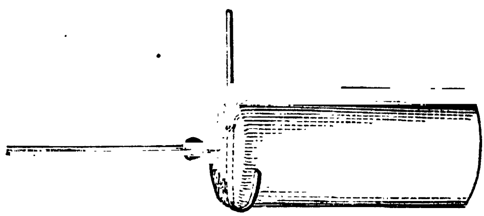
* In other cases the point *c* is seized by a pair of forceps by another workman, and drawn out, when the application of a cold iron causes a circular crack all round, and the piece is broken off.

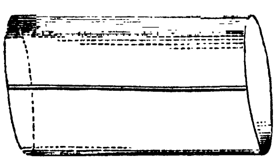
tion by which the peculiar form is given to this kind of glass, a general sketch of the blowing-furnace, &c., is shown in Fig. 34; *a* is the furnace, *b* the working hole, and *c c* are short flues over the working hole, to carry off the flame, &c., from the workman into the cone; *d* represents a long plank upon which the workman stands over the pit *e*, as he twirls the pipe and glass cylinder *f f* until it assumes the form, Fig. 31.

According to the size of the cylinder, it may be either blown at once, or it will require to be re-heated several times. When very long and wide cylinders are blown, the lower portion is liable to become too thin; an extra portion of glass must then be incorporated with it before the opening process.

The neck and curvature where the pipe was attached to the cylinder have now to be removed, in order to spread the whole out in the form of a plate, and the cylinder must be cut open lengthwise. The cylinder, supported by an assistant upon a wooden rod is, therefore, turned round two or three times in the curve of a bent iron, heated to redness, as shown in Fig. 35, and a drop of water is allowed to fall upon the heated line, which fractures the glass and detaches the cap. In a similar manner, but in a straight direction, a crack is made longitudinally, and the cylinder is then prepared for spreading or *flatting*, Fig. 36.

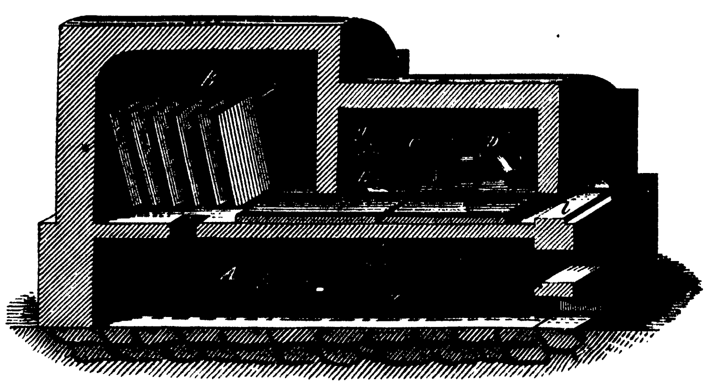
Fig. 35.





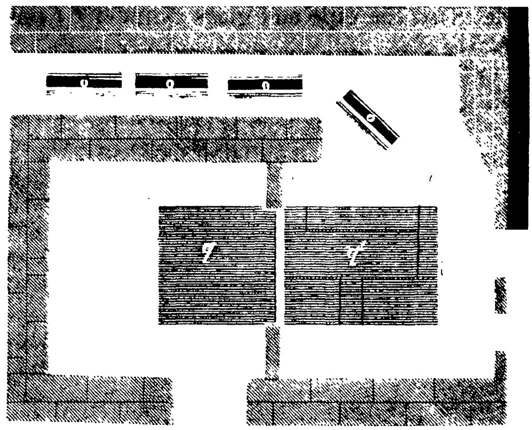
Furnaces constructed purposely, in separate buildings, are necessary for this operation, the principal parts of which are shown in perspective at Fig. 37, and in horizontal section over the

Fig. 37.



sole in Fig. 38. The arched space *A* which extends the whole length of the furnace, comprises the ash-pit *a*, and the grate *r*; the

Fig. 38.



former is accessible by the door *b*; the stokage is performed through *d*. The flame enters the upper space through the apertures *c*, *c*, *c*, *c*, and first plays upon the flatting-hearth *C*, before entering the annealing or cooling-furnace *B*—which is also heated directly by the fire—when it escapes through the flue or channel *D*, by which the cylinders are introduced to be subsequently removed at *i*. The flatting-hearth and the cooling-furnace are connected with each other by a low arched, wide aperture *E*, for the passage of the plates, as well as by a smaller, higher opening *g*, for the admission of the flame. The heat in the interior can easily be regulated by pushing plates over the apertures *c*, *c*, and opening or closing the aperture *k*. The flattener stands in front of the aperture *l*, the workman engaged at the cooling-furnace before *m*, and an assistant in front of *i*, who pushes the cylinders *o*, *o*, *o*, *o*, along the railway *p*.

The most essential part of the furnace, however, is the *spreading-plate* or *flatting-stone*, *q* and *q'*. This must be perfectly even, without any roughness or inequalities which would scratch the glass or make it lumpy; it must be inalterable in the fire, and of a size somewhat larger than the flattened cylinders.* A plate of this description is usually manufactured from fire-proof clay mixed with cement† strongly beaten during drying, then burnt, and lastly ground smooth; it is laid upon a bed of sand and in contact with a second table of the same sort in the cooling oven. To make quite sure that no injury

* In some manufactories this artificial plate is replaced by natural stones, where such can be obtained possessing the requisite properties, as those from Godstone in Surrey.

† Either ground fragments of burnt clay of the same kind, or fine sand, or ground quartz.

shall be sustained by the plates upon the flatting-stones, it is customary to cover this previously with a *Lager*. This is the name given to a thick plate of glass expressly blown for this purpose. These lagers are soon devitrified, which is of no moment, so long as the surface remains smooth; this, however, does not last long, and frequent renewal of the lager becomes necessary. Lastly, to prevent the cylinders from attaching themselves to the lager, the flattener, in some manufactories, throws a handful of lime into the furnace, which is carried as fine dust by the flame and spread over the lager. The temperature in the flatting-furnace must only be just sufficient to soften the cylinders; whilst in the cooling-furnace it must not attain that point.

The spreading operation is commenced by introducing the cylinders into the warming-tube *D*. The further the cylinders are pushed forward by those succeeding them the more they become heated, until they begin to soften on reaching the flatting-stone. They are then taken by the workman with a rectangularly bent iron, and placed upon the lager with the cut side uppermost, where they open of themselves, and are easily straightened and made even. For this latter purpose, a rod of iron, furnished at the end with a wooden polisher (Fig. 39), is employed, and this is dipped into water each time it is used. When all the curvatures and lumps have been reduced, the sheet is pushed backwards into the annealing-oven, where it cools down and is placed in an upright leaning position by another workman. Between every 30 or 40 sheets, an iron rod *s*, *s*, *s* (Fig. 37) is inserted, and the operation is continued until the whole furnace is filled.

Fig. 39.

The principal imperfections in the operation of flatting, arise from the want of an appropriate and lasting flatting-surface; the flatting-stone is durable, it is true, but is too hard to preserve the glass from scratches; on the other hand, the lagers are well adapted to the object for which they are intended, but their durability is uncertain, for when the devitrification to which they are subject is advanced to a certain stage, they become too hard and their surface becomes roughened. According to Lippert, the lagers may be replaced by artificial stone plates which are exceedingly thin and composed of equal parts of quartz powder and pipe-clay. These are carefully polished and surrounded by cast-iron frames.

In England, the cylinders, as they are made, are placed in a convenient locality on their ends, the floor being paved with wood to prevent the loss by breakage as much as possible. The next step consists in placing the cylinder in a "spreading furnace," where it is heated until it begins to collapse, when, by running a cold iron on the inner bottom side, or dropping a little water on its edge, it is split

lengthwise. Such a cylinder is now placed on a flatting-stone with a convex surface, in the same furnace, and to prevent the sheet of glass from bending over such a surface, which would destroy its regularity, the workman continually alters its position, so as to expose all sides of the glass to the action of the fire. This motion seriously injures the surface of the glass, while it is also heated to an unnecessarily high point to enable the sheet to resist the cooling action of the air in removing it to the annealing-arch.

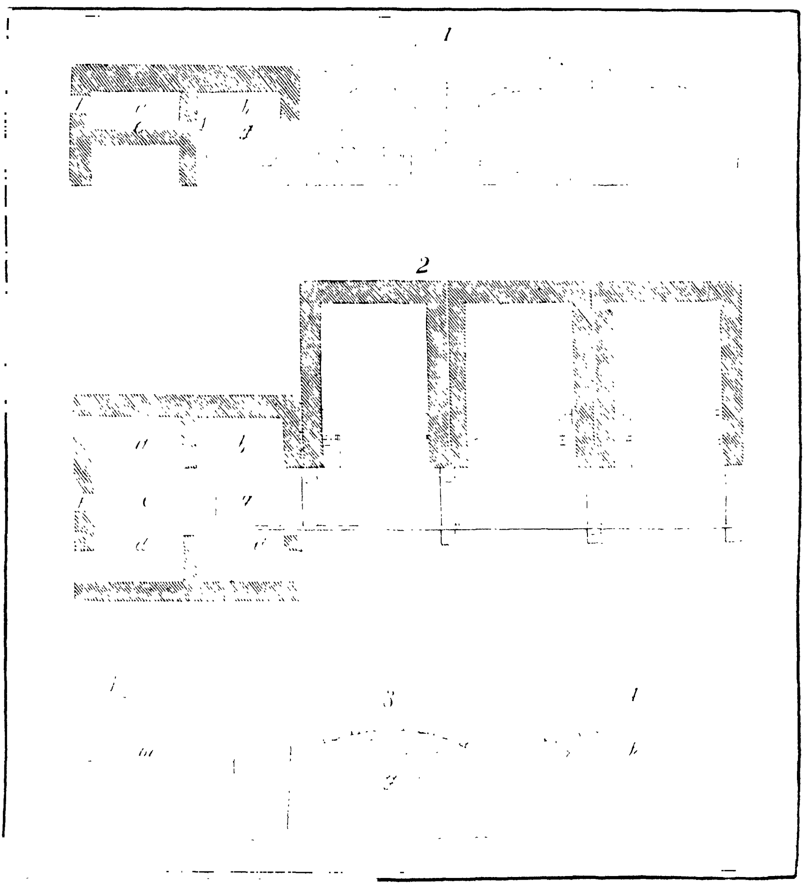
Mr. Hartley, the talented manufacturer at Sunderland, has proposed the following arrangements, which are much superior to the plan described above.

Fig. 40, I, is an elevation of a flatting-furnace in section, with three annealing arches of the ordinary description.

Fig. 40, II, is a ground plan of the same.

Fig. 40, III and IV, are elevations of two end views of the flatting-furnace; *a b* is the spreading furnace divided into two compartments

Fig. 40.



by the partition *c*; *d d* are two sets of fire bars, on which wood must be burnt; *e* is the spreading or flatting-stone of the furnace, which must be perfectly smooth and even, and made of sandstone from Godstone, in Surrey, which is the best adapted for this purpose; *i* is an opening through which the cylinder is placed in the furnace previous to being laid on the flatting-stone *e*; *h* is the opening through which the workman spreads the cylinder into a flat sheet of glass; *f* is the opening through which the sheet of glass is removed to the table or bed *g*, in the compartment *b*. The upper side of the table *g*, is made of stone similar to that employed as the flattening surface. It is fixed to an iron frame-work on wheels, and is kept at a proper degree of heat by remaining in the furnace, as shown in the drawing. The carriage runs on a railway in front of the annealing-arches, where the sheet is transferred in the usual way.

The cylinder is placed on the flatting-stone, and is split lengthways by passing a red-hot iron bar *k*, from end to end, having previously sprinkled a little charcoal powder on the inner surface of the cylinder. It is now spread out into a sheet by pressing the same on the flatting-stone, by means of a small block of elderwood, fixed on an iron bar *m*. The temperature at which the flatting is performed, is such, that the operation does not occupy more than a minute.

Mr. Hartley has lately introduced two improvements in this operation. One consists in making part of the floor of the compartment *a* to consist of a movable stone about 10 inches in diameter, on which the cylinder is placed. It is gradually exposed on all sides to the action of the fire, by causing the stone to revolve on its axis, and thus the objection to the previous plan is avoided where one side of each cylinder became so much hotter than the other.

When the sheets of glass are to be polished, the injury to the surface is not so much an object as to have them perfectly flat, and the air which lies between the flatting-stone and the cylinder, renders this a difficult operation. Mr. Hartley's other improvement is intended to remove this difficulty, which is accomplished by making holes, about the eighth of an inch in diameter, all over the flatting-stone about an inch apart.

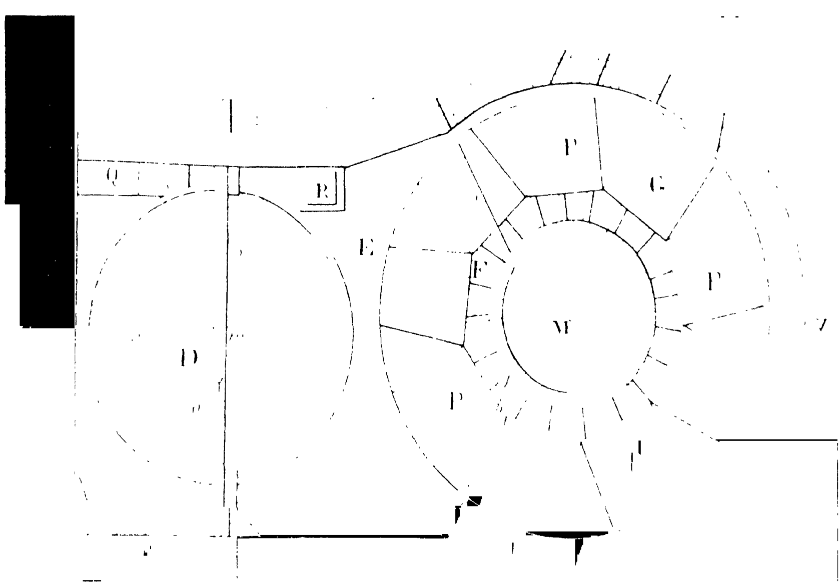
Mr. Chance has patented another modification of this process, the chief object of which is to prevent the removal of the sheet of glass into the open air until annealed. This he accomplishes by having several flatting-stones, at different degrees of temperature, and, lastly, by loading or piling his wagons with the sheets of glass which are made to move slowly through a long annealing arch, similar to those employed for annealing flint-glass articles, kept hottest near the flatting-stones or "lagers;" in this way the glass enters the flatting kiln in the form of a cylinder, and does not leave the other furnace until fully annealed, without ever coming into the open air.

The most recent improvement is that of Mr. Farthing, in which the kiln is heated by means of flues arranged under the floor, around the walls, and over the arch. All deposit of dust or hard particles

from the fuel on the surface of the glass is avoided, and a less expensive fuel answers the purpose.

[*Franck's Annealing-Oven.*—In 1843 Mr. John Franck, of Millville, N. J., received a patent for a flattening and cooling oven for cylinder glass, of which a plan, taken at the level of the flattening and cooling planes, is exhibited in Fig. 41. Above these planes the oven is arched over in the usual manner by a cylindrical arch at the narrower part, and by a dome at the broader circular end *V*. At the end *U*, just above the level of the flattening planes, is an opening in the end wall of the furnace for inserting the cylinders, and for manipulating the glass. *D* is a horizontal wheel, resting on a pivot at the bottom of its axis in a step, placed at a sufficient distance below the upper horizontal surface of the wheel to be out of the reach of any injurious heat, and the axis *m* is sustained in the vertical position by a pair of cross-bars, through the intersection of which it passes. This wheel is covered by the four clay stones *o o o o*, each 31 inches wide and about 40 inches long, made perfectly smooth. By means of gearing on the lower part of its shaft, and a bevel wheel, having its axis projecting outside of the furnace, a rotary motion may, at pleasure, be given to the wheel *D*, so as to bring the several flattening stones successively to the front opposite to where the glass is to be placed upon it. In the side of this oven is a furnace *Q*, by which it is heated. *Y* is a suspended wall or mantle connected by bolts to the arch above, and coming down nearly to the surface of the wheel *D*. The part of the furnace between *Y* and *U* is called the *flattening-oven*. Beyond the mantle *Y*, and between it and the two suspended mantles *e* and *f*, is

Fig. 41.



the space *E*, called the *heating-oven*; the fireplace of which is indicated by *R*. When a cylinder of glass has been flattened on one of the stones *o*, the wheel *D* is made to revolve, by means of the gearing above mentioned, so as to carry the pane under the mantle *Y*, into *the compartment E, where it receives the proper annealing heat*, and is transferred *to one of the stones P P P* on the *large cooling wheel F*, revolving also on the top of an upright shaft *M*. This wheel is 13 feet in diameter, and contains 9 cooling-stones, each 36 inches long and 29 inches wide. It is made to revolve by toothed wheels and pinions, so as to bring the several cooling stones successively to receive the plates from the heating-oven, and conveying them under the mantle *e* into the cooling oven *G*. The cooling-wheel is made to revolve by gearing similar to that which moves the flattening-wheel, carrying the plates quite round the cooling-oven, until they arrive opposite to the opening *I*, where they are withdrawn, having occupied about two hours in annealing and cooling. This annealing-oven possesses the advantage of far greater compactness than most others which have been devised for the same purpose. It does not involve the necessity of setting the panes on edge to undergo the annealing process.]

Furnaces.—The Messrs. Chance, of Birmingham, have recently patented a new improvement in glass reverberatory furnaces. The improvement consists in building a second arch above the ordinary reverberatory arch, which causes the flame, after having been reverberated, to pass over the back of the reverberatory arch, and from thence to the chimney.

Insertion of Sheet Glass into the Annealing-Kilns.—Instead of pushing the sheets of glass into the annealing-kilns, as is now the usual practice, and which requires that a portion of the edge of the sheet should be turned down and allowed to cool, Messrs. Chance propose to use a long wedge-shaped rod carrying two vertical supports, between which another rod turns parallel with the first, and which is furnished at one end with a handle, and at the other with a grip of wood, so that when the workman has introduced the wedge portion of the lower rod underneath the plate of glass, he turns the handle of the upper rod, and brings the grip down on the upper surface of the plate, which is thus firmly held, and can be carried thus to the kiln.

Crown-Glass (Mondglass).—In the manufacture of crown-glass, in circular discs, a flattened vessel is first blown in front of a furnace specially constructed for the purpose, and this is converted, without any interruption of the process, into a round disc, thickened in the centre.

Fig. 42 represents a general view of the crown-glass "houses," in which *a* is the *melting-furnace*, shown more in detail in another sketch; *b* is the "*cave*," a large underground flue; and *c* the "*cone*" for creating draught; *d d d* are front views of the *annealing*-arches; *e* the *blowing*-furnace; *f f* the fire-places, and *g g* the various openings through which the sheets of glass are placed in the annealing-arches; *h h h* show the roofs of the buildings, partly resting on the cone; the whole giving thus a general [illegible]

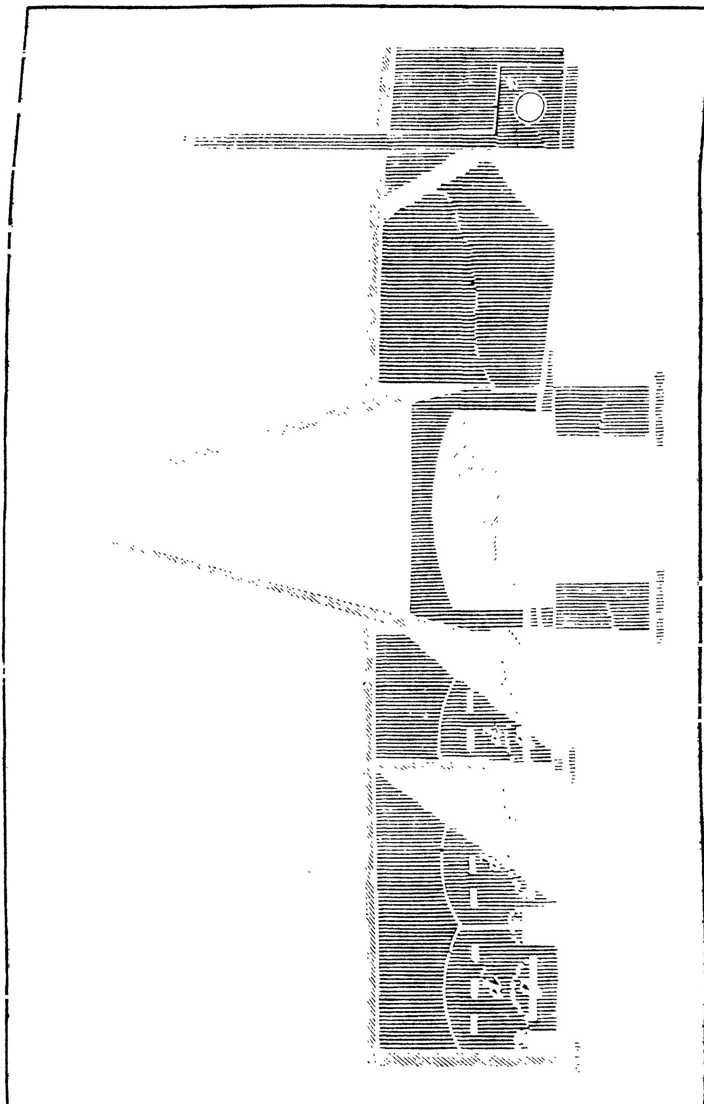


Fig. 42.

Fig. 43 shows a ground plan of the melting-furnaces and the elevation of an end and side; *a a a a* are the stone pillars which sustain the cone; *b b b b*, the walls of the furnace; *c c*, the grate bars upon which the fuel lies; *d d*, the "sieges," or position which the melting-pots occupy, one opposite each opening *e e e*; *g* is an elevation of the sides *f f*; and *h* an elevation of the ends *i i* of the furnaces; *k k k* are temporary openings to enable the workmen to insert large iron levers to assist in placing the pots, which are carried on a machine, in a red-hot state, into the furnace through the

Fig. 43.

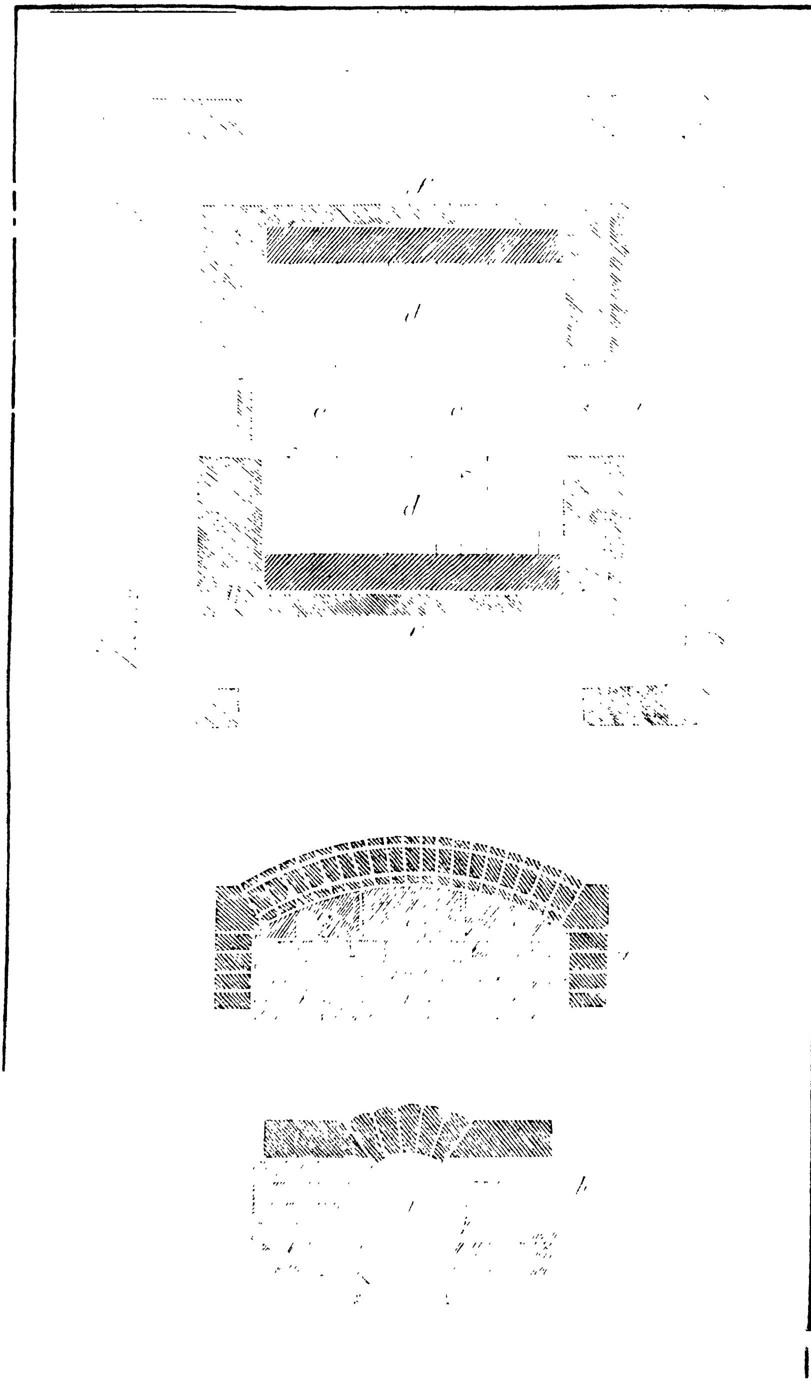
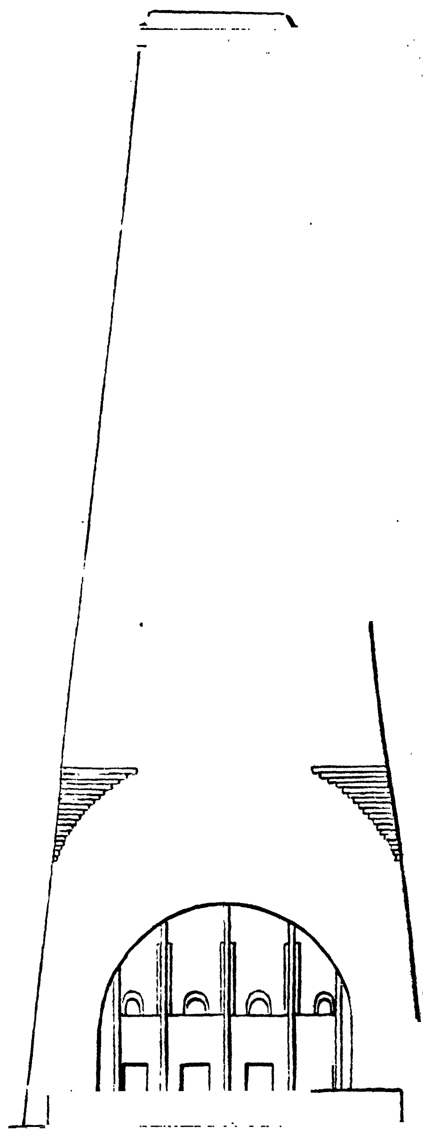


Fig. 44.

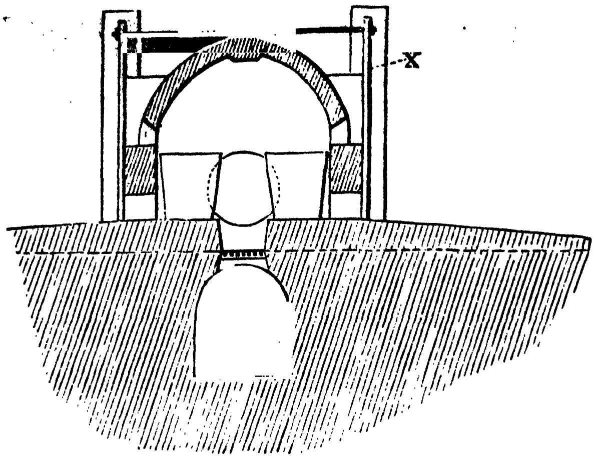


other temporary opening *l*.

Mr. Charles Cowper, late of Messrs. Chance, of Birmingham, supplied for this work the two drawings, Figures 44 and 45. Figure 44 represents an elevation of a crown-glass furnace with cone complete; Figure 45 shows the manner in which the flame from the fire enters the furnace in the centre between the pots, and also the manner in which the arch is bound together above.

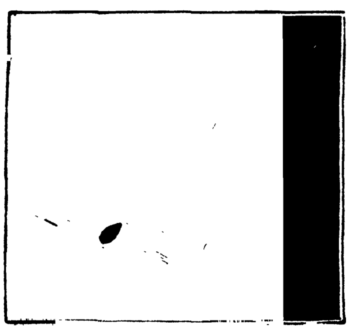
When a certain weight of glass *a*, Fig. 46, has been collected or gathered from the pots on the end of an iron tube *b*, it is fashioned into a peculiar form, as shown in Fig. 46, on a solid plate of cast-iron *c*, also called a marver, although used for a different purpose to that mentioned previously (p. 47). Previous to the operation of "marvering," the workman cools the iron pipe, which has become heated by being exposed in the melting-furnace, and this operation might be done in the following way, as less expensive than that in common use. Fig. 47, *a*, is a cistern filled with water (by a steam-engine pump) to the under side of which is fixed an iron pipe *b*, pierced with a number of small holes *c c*, and situated over a tank *d*, to collect the water, whence it can run off by a waste-pipe *e*. Two small iron supports *f f* are attached to each end of this tank, so that the workman, by placing the hot pipe on them, brings it exactly under the shower of water, which he regu-

Fig. 45.



lates by the cock *g*. By moving the pipe to and fro, it is cooled so as to enable the workman to handle it.

Fig. 46.



The marver (Fig. 46) *c*, is placed on rollers for the convenience of moving it from place to place as required. When the mass of glass has assumed the proper form, a boy blows through the iron tube, while the workman continues to roll the ball upon the marver. That part of the glass which is attached to the end of the tube, and which subsequently becomes the rim or outer edges of the sheet, sometimes, from mismanagement, forms a very thick rim, thereby injuring the value of the glass for sale. Mr. Ewing has invented a very simple contrivance for preventing this defect. He applies to the back of the marver, an instrument which he calls a cutter, as shown in 1 and 2 (Fig. 48). It is made of iron, and sharpened by means of a file. The form *a* is not necessary, as it may be constructed similarly to that shown at *b*. They are attached to the marvers by means of bolts or screws.

Fig. 47.

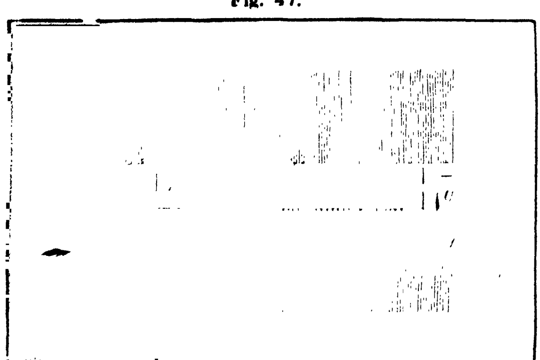
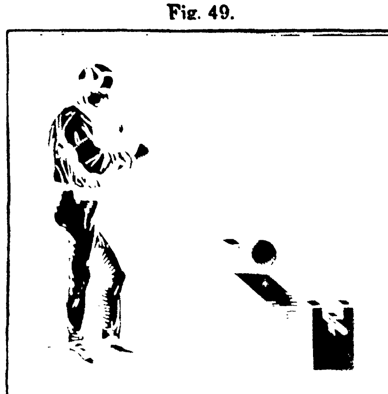


Fig. 48.

The moulded glass is placed on the cutter at the neck of the piece* close to the pipe, while the boy is blowing through the tube, and it is thus prevented from thickening at this point. During the subsequent re-heating and blowing of the mass, it is kept in a similar position on another cutter, 4 (Fig. 48), for the same purpose.

Mr. Chance proposes to accomplish the same object by attaching a bar of soft wood, as that of the pear-tree, to the front side of an ordinary marver at *c*, Fig. 48, 3. On the upper edge of this bar, which is about 6 feet long, 6 inches wide, and 1 inch thick, small grooves are cut, 2 inches wide by ¾ inch deep, to receive the neck. The bar is allowed to drop below the marver while the workman fashions the mass, but when he commences to blow, it is raised by a boy, so that the neck rests in one of the grooves. This is easily managed by making one end of the bar movable on an axis, while the other rests on a pin which can be removed at pleasure.

Fig. 49.

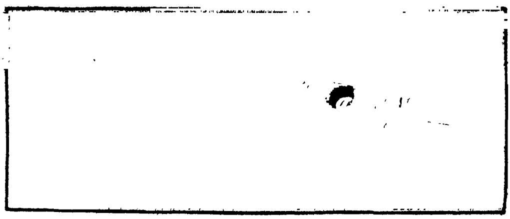


During the previous operation of "marvering," the mass of glass is fashioned so as to give the outer extremity a conical form, the extreme end of which becomes the outer axis of the globe during the operation of blowing. This outer axis is called the "bullion," and during the expanding of the globe, the workman rolls this bullion along a straight edge or bar, which is called the "bullion-bar," as shown in Fig. 49. This continual motion of the glass, on the bullion-bar, forms more or less waved lines round the centre

The thick globe of glass is technically termed the "piece."

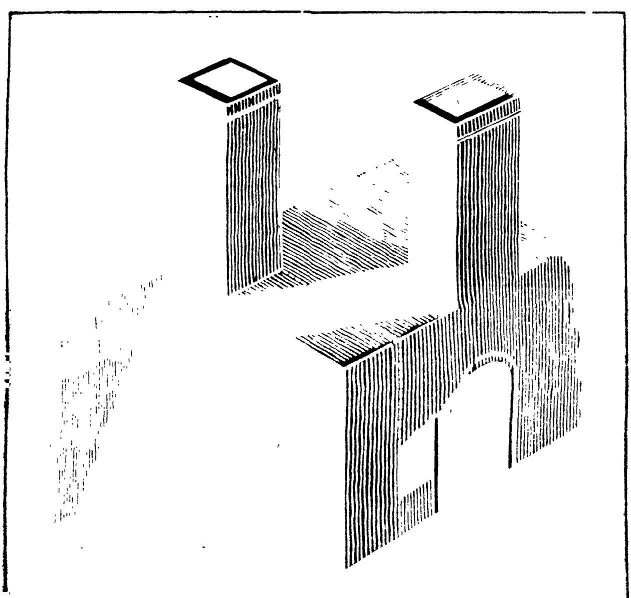
of the table of glass which injures its quality. The drawing, Fig. 50, represents a contrivance of Mr. Hartley for removing this defect; *a* is the globe of glass, attached, by its neck *b*, to the ordinary iron tube *c*; but instead of the bullion *d* resting on the bullion-bar in the ordinary manner, it is supported by the tube *e*, on the end of which the workman causes it to revolve; *f* is a shield to protect the boy who holds the instrument *e*, from the effects of the heated globe.

Fig. 50



The piece of glass, after the above operation, is re-heated in the blowing-furnace (Fig. 51) at *a*, and expanded by the workman blowing through the iron pipe, until it is so far cooled as to require another

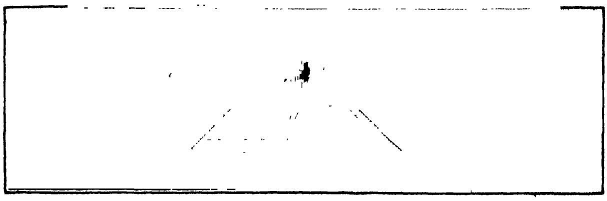
Fig. 51



"heat," which is taken at *b*. When it has been blown to the proper size (Fig. 52, 2), it is again exposed to the heat of the furnace at *b*, when the workman, resting the pipe on an iron support, during which time the neck remains cool, causes the glass globe, by a peculiar motion of the pipe, to assume the shape shown in Fig. 52, 3. This last operation is technically termed "bottoming the piece." It is then removed to a framing (Fig. 53), where it rests on its edge on

Fig. 52.

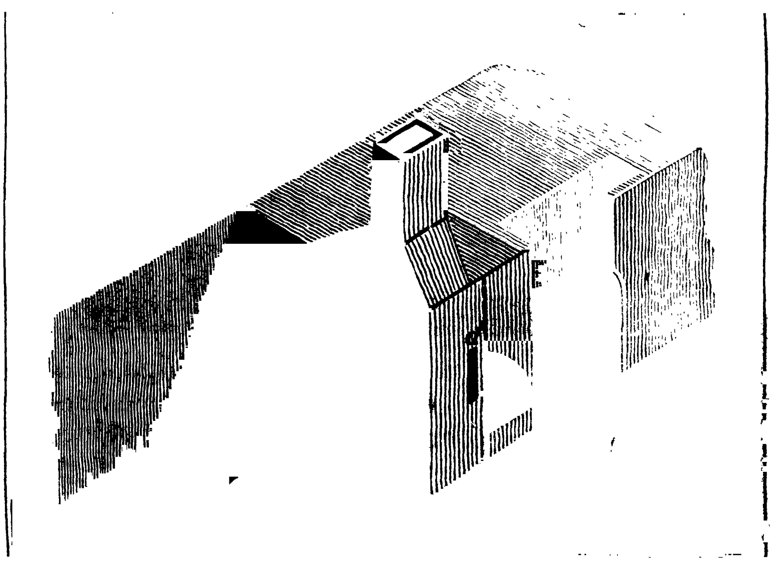
Fig. 53.



some ground charcoal and cinders, *a*. Another workman then attaches a strong iron rod, with a quantity of melted glass at its end, to the centre of the piece, as at *b*. The "blower" now touches the neck of the piece at *c*, with an iron rod previously dipped in water, and by a smart blow on the iron tube *d*, detaches the piece, leaving the neck open, as shown in Fig. 52, 4.

The "piece" is now removed to the "flashing" furnace, Figs. 54 and 55. The thick neck is first heated at the opening *a*, whence a powerful flame is issuing, and which is shown in Fig. 57 more in detail. Fuel is placed on the grating *b*, Fig. 54, for the purpose of warming the "piece," while the neck is heated from the larger fur-

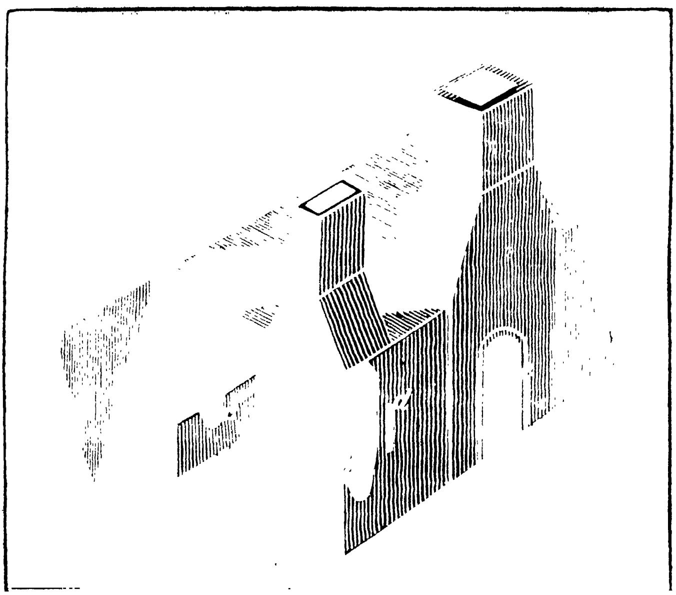
Fig. 54.



nace through an opening *a*. During the working, the door *c* is closed, as in Fig. 55. As soon as the neck is sufficiently soft, a boy inserts a flat iron tool through the opening *d*, to smooth the roughness left in the neck by breaking it off as described above. This part of the flashing-furnace is called the *nose hole*, the construction of which Mr. Hartley has improved, by introducing the air above the ignited fuel instead of from below; and the dust and injurious vapors are thus prevented from entering and destroying the glass, in the "neck of the piece."

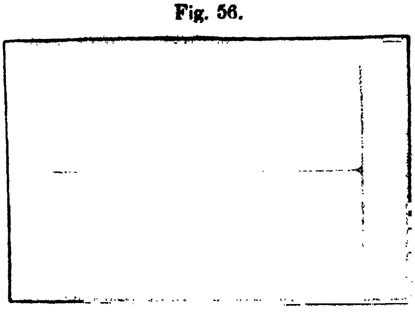
The "flashing" operation is conducted in the other compartment of the furnace, shown in detail in Figs. 54 and 55 at *e*.

Fig. 55.



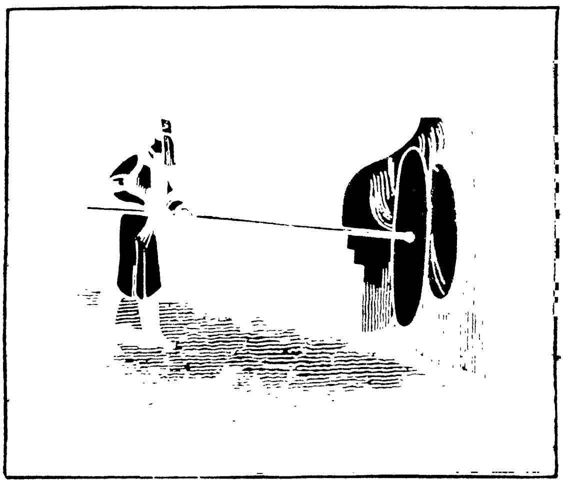
When the neck has been sufficiently heated at the nose hole, the bell-shaped vessel is brought in front of the other opening *e*, where it receives the full heat of the flame, and the pipe is then made to revolve with the greatest possible rapidity. The action of this rotary motion upon the softened glass is easily conceived. The centrifugal force communicates to the particles of glass a tendency to fly off at a tangent, and to arrange themselves in a circular plane perpendicular to the axis of rotation. The mouth being the

Fig. 56.



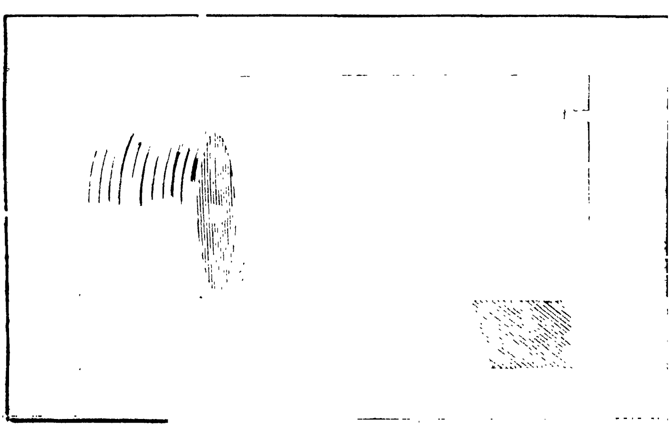
softest part, first expands, and this quickly increases until the whole suddenly opens into one sheet of glass, Fig. 56, of about 6 feet in diameter, which, with the exception of the central portion, is of nearly uniform thickness. It is obvious that a sheet of such dimensions must quickly fold together in the soft state, if the rotary motion is not kept up. The workman, therefore, continues the rotation after the removal of the sheet from the flame of the furnace, until it reaches the annealing-oven, where it is placed on a small circular bench, and is detached from the rod by means of a pair of strong shears, leaving a mark called the "bullion," or bull's eye. Fig. 57 shows a workman em-

Fig. 57.



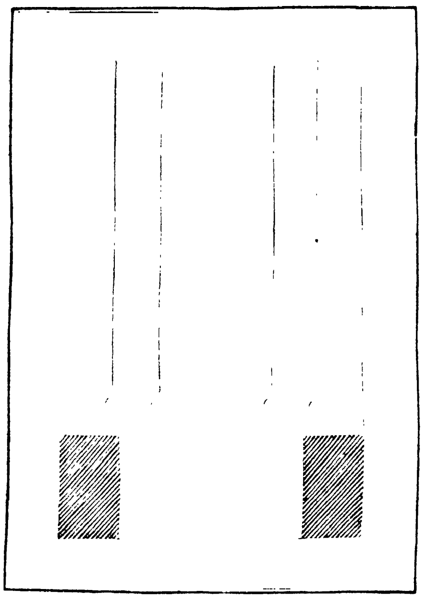
ployed in the operation of flashing. Another workman, who has charge of the annealing, now raises the "table" of glass upon a large *fork-like* instrument, and carries it through the opening *a* (Fig. 58),

Fig. 58.



while an assistant cautiously lifts the near edge, and brings the table into an upright position in the annealing-arch, as shown at *b*. The tables stand thus on their edges, upon two strong parallel iron supports, *c c*, *c c*, (Fig. 59), which run the whole length of the annealing kiln. Fig. 60 shows the fire-places *d*, *d*, and *e*, *e*, the ash-pits; *f*, *f*, *f* are the exits for the flame and smoke into the chimney.

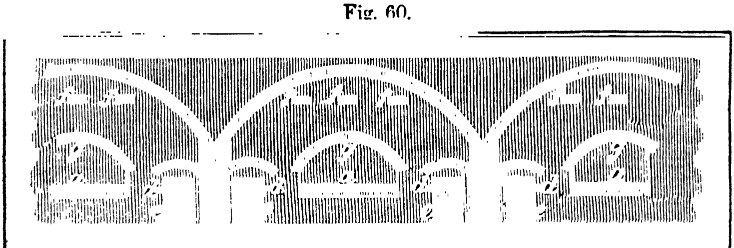
Fig. 59.



The glass, after remaining in the kiln for a considerable time, during which the cooling has been carefully regulated, is withdrawn, by removing the temporary stoppage *g*, so as to enable a workman to go inside, and hand out each table on the outside to an assistant.

It cannot be denied that crown-glass, manufactured in this manner, and not subjected to the injurious action of the lagers, &c., possesses a very superior lustre and a less undulated surface than cylinder-glass; it can also be made much thinner than

Fig. 60.



the latter kind. But these advantages are counterbalanced by a considerable waste in cutting it up into panes, which partly arises from its circular shape and the thick lump in the middle, or the *bull's-eye*, which is seldom applicable to any useful purpose, whilst the flatted plates can be used entire. On the continent of Europe, the manufacture of crown-glass in tables is almost entirely superseded by that of cylinder-glass; in England, however, it is still very generally carried on, not so much for technical reasons, as on account of the excise duty being levied on the weight of glass manufactured, and not upon the number of sheets, and more panes can be obtained from the same

weight of this variety of crown-glass than from the cylinders, in consequence of its lesser thickness.

PLATE-GLASS.

Historical.—An attempt was made in the glass-houses, in Sidon, to manufacture mirrors from an opaque black mass of glass, but with so little success, that metallic mirrors continued in very general use. Mention is first distinctly made of glass mirrors prepared from plates coated with lead by the Franciscan Monk, John Peckham, in his "*Perspectiva communis,*" which appeared in 1279. Glass globes filled with lead are said by Porta and Garzoni, to have formed a considerable article of commerce at Nuremberg in the beginning of the 16th century. The art of covering plates of glass with tinfoil, was also discovered and carried on at Venice in the same century, and was introduced from thence into France in 1665, where it was much extended by Abraham Thevart's discovery of the mode of casting plates in 1688, and brought to its present state of perfection. Plates for mirrors are now made in both ways, by *blowing* and *casting*. The operation of blowing and flatting glass for mirrors is similar to that already described for window-glass, with some slight modifications rendered necessary by the greater size of the plates. The casting of plate-glass is a perfectly distinct operation.

The thickness of these plates, which are often ten feet and more in length, must of necessity correspond with their extension; and that the light may be perfectly reflected from the metallic surface at the back, they must be as transparent and colorless as possible. To conform to such important conditions, the composition must consist of the purest ingredients, and afford a glass, the surface of which is quite unalterable when exposed to the air; if this is not the case, the plate becomes dull, loses its polish, and with this its transparency.

A good mirror should also reflect an image in its true and natural shape, and no distortion must occur, which invariably happens, if lumps or waves in the glass produce an irregular reflection of the light. The highest degree of purification is also indispensable, so that the manufacture of plate-glass is attended with quite as much difficulty as that of optical glass, and is very much more extensive.

Composition of Plate-glass.—Although potash imparts much less color to the glass than soda, yet the latter is very generally employed in this branch of the manufacture, as it communicates a much greater degree of fluidity and facilitates both the fining and the casting; this will be seen from the following recipes:

COMPOSITION USED AT ST. GOBIN.*	COMPOSITION ACCORDING TO BASTENAIRE.	COMPOSITION ACCORDING TO SCHULTES.
100 lbs. pure sand (from Senlis)	100 lbs. white sand	100 lbs. sand
35 " pure salts of soda	60 " salts of soda	75 " purified potashes

* Plate glass manufactory of Paris. The composition used at this manufactory is differently stated elsewhere—thus: white sand 300; dry carbonate of soda 100; fallen lime 43; cullet 300

COMPOSITION USED AT S. GOBIN.	COMPOSITION ACCORDING TO BASTENAIRE.	COMPOSITION ACCORDING TO SCHULTES.
5 lbs. lime (crumbled)	13 lbs. carbonate of lime	33 lbs. lime
100 " broken glass	100 " broken glass	3 " common salt
discolorizing matters	1 " perox. manganese	7 " nitre
	½ " smalt	1½ " arsenic
		perox. mang.

The last of these mixtures is an instance of a bad selection of materials; it comprises far too much lime and potashes, and so much discolorizing substance, as could only be called for by very great impurity in the ingredients. The most suitable proportions are 7 parts of dry carbonate of soda, and 3 parts of lime; or 6 parts of purified calcined potashes, and 3 parts of lime to 9 parts of sand,* and to these a moderate quantity of discolorizing matter is added, and broken glass, in proportions varying with the construction of the furnace and its heating power.

In many places the mixture is fritted (in England); in others (as at St. Gobin, in France), it is composed of such pure materials that it can be placed cold in the pot in three separate charges, many workmen being employed at once, and the greatest possible expedition used to prevent the furnace from cooling. Every furnace is supplied with two kinds of fusing pots or crucibles. The one kind is round, as represented in Fig. 61, and the other quadrangular, and is called the *cuvette*, Fig. 62. The former are used for melting, and must consequently be larger than the cuvettes, which are intended for fining and perfecting the glass. In England, pots are used from 3 to 6 feet high; they are open at top when wood is employed as fuel; but are covered, as is the case with flint-glass, when coal is burnt.† As the cuvette must contain enough glass for one casting, and not much more, there are two sizes in use, one for the large and the other for small mirrors. During the melting of the mixture in the pots, the cuvettes are placed empty in the furnace; as soon, however, as the whole charge is in a state of fusion, the cuvettes are removed by means of tongs fitting into the groove *b*, Fig. 62, and cleansed from all impurity, and from the residual glass of the last operation, by a scraper; they are then replaced upon the sieges, and the ladling operation commences. The surface of the metal in the pots is skimmed off, and the liquid glass is ladled into the adjacent cuvette with a copper ladle, care being taken not to disturb any grains of sand or lumps that may have settled down at the bottom of

Fig. 61.

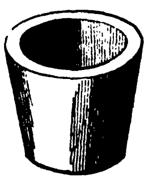
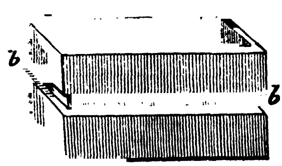


Fig. 62.



* The proportions here recommended do not correspond with those used at St. Gobin, where the alkali and lime together are to the sand as 40 : 100 in the mixture, and the glass produced at that manufactory is of excellent quality.

† The pots used in England for plate-glass are seldom or never 6 feet high, and are open under all circumstances.

the pot. Thus, at the very commencement, a kind of double purification is effected: the infusible portion is left untouched, and the glass is well mixed by the agitation of ladling. The ladle becomes so hot, after having discharged three portions, that it must be placed in water and exchanged for another, as there is fear of its being attacked. The drawings of a plate-glass furnace exhibit the manner in which the fusing pots are arranged, and also how they are inserted and removed.

Fig. 63.

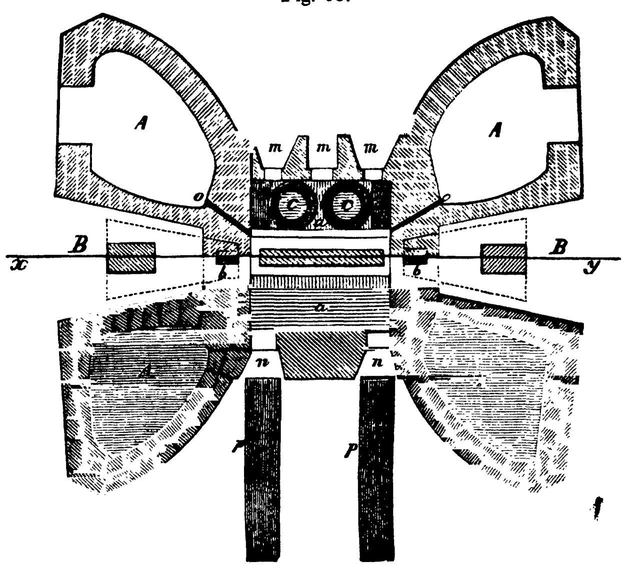


Fig. 63 is a horizontal section at the height of the sieges, to the right of x y, and somewhat lower to the left, through the holes for the cuvettes. Fig. 64 is a perpendicular section through the line x y. The melt-

Fig. 64.

ing-furnace is surrounded by four side furnaces *A A A A*, used for burning and heating the pots, and so arranged that the whole length

of the sides with the siege *a* is left open and free of access. Thus the two remaining sides are only accessible by the narrow passages *B B*, and these are connected with the large apertures *b b*. These apertures are used for the insertion of the pots *c c*, and, at the same time, for stoking the fire; for the latter purpose they would be too large, and allow too much heat to be lost: they are consequently bricked up above, and closed in front by slabs of clay, with the exception of the small apertures *e e*. A grate is indispensable when coal is used, but this is not the case when wood is the ordinary fuel. The flame travels from the melting furnace, after passing between the sieges, and heating the pots *c c*, and the cuvettes *i i*, through the flues *o o* into the side furnaces *A*. Two rows of holes are left in the free sides of the furnace. By means of the upper working-holes, *m m m*, the melting-pots are accessible for the purposes of ladling; through the two lower holes, *n n*, the cuvettes are inserted or removed upon the iron slabs *p p*, which must consequently be exactly upon the same level as the sieges. All the holes can be closed by movable plates at pleasure. The draught can be regulated through *r r*, and the ash collects in *s s*.

Fig. 65.

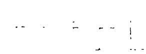
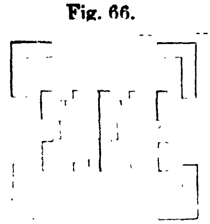


Fig. 66.



Figs. 65 and 66 represent, in elevation and plan, a novel mode of constructing two furnaces abutting each other within one cone, each furnace having only one teaze-hole for the admission of fuel, as seen at *t t*, Fig. 66. By this arrangement, the proportion or capacity of each furnace as compared with the area of the sieges *T T*, is greatly diminished, and effects a more powerful concentration of reverberated heat and economy of fuel, which advantages are further augmented by the application of hot air, forced by an engine into the furnace below the grate-bars, the ordinary cave at each end of the furnace being kept closed.*

Since the repeal of the excise duty on glass in England, the expense of fuel has become an important item in its cost, and the first effort on the part of the manufacturer to economize in the consumption of coal by mechanical arrangements, has originated with Mr. Chance. If 75 per cent. of the whole fuel thrown into a blast-furnace is lost, we shall not be far from the truth in asserting that at the very lowest estimate upwards of 90 per cent. is wasted by the present construction of glass-melting furnaces.

The following are Mr. Chance's arrangements: Fig. 67, is the longitudinal section; Fig. 68, a plan in section; Fig. 69, a plan of the furnaces in horizontal section; and Fig. 70, a transverse section of a glass-melting furnace constructed according to this plan. *a a* are

* This, together with a whole series of improvements in the implements and machinery employed in the manufacture of plate-glass, which will be noticed as we proceed, has been lately made the subject of a patent by Messrs. Nicholson and Wadsworth, and the English Editors were indebted to the kindness of Mr. Carpmeal, Editor of the Repertory of Patent Inventions, for the cuts illustrative of these improvements.

two fire-places, one at each end of the general building, and *b* is a bridge to divide them; *c c* are the arches upon which the pots rest, with their working-holes *d d*; *e e* are the usual openings by which to get at the pots in setting them, &c.; and *f f*, the openings at the ends through which they are introduced in the ordinary manner. There are spaces left between the arches *c c*, through which the heat and flame of the fire pass, and play round the pots in making their escape through the working-holes *d d*, into a cone in the usual way. Mr. Chance thus attempts to bring the heat more in contact with the pots, as is done in a flint-glass furnace, but in a somewhat different manner.

Fig. 67.

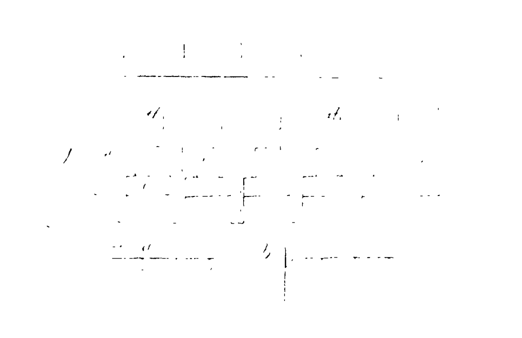
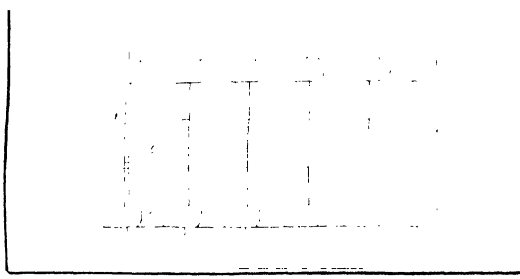


Fig. 68.



In the attempts to save fuel, it does appear strange that, after the

Fig. 69.

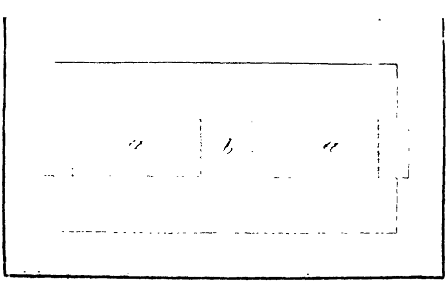


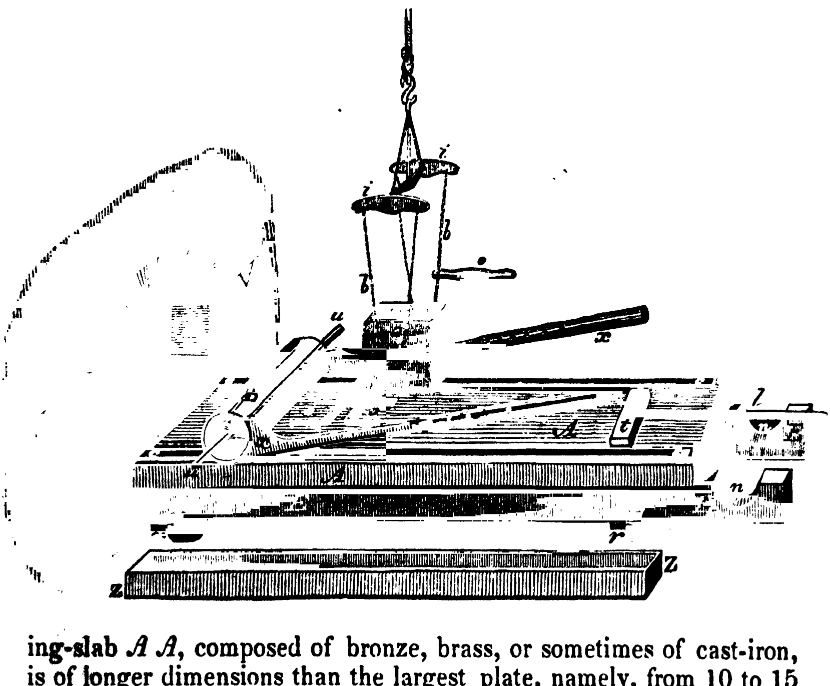
Fig. 70.

striking economical results attending the use of hot air in iron-smelting, &c., no one should have applied it to glass-furnaces in England, and more especially as it has already been done in Germany with a saving of 20 per cent.

The melting is generally accomplished in 16 hours, but the fining which succeeds the ladling process must be kept up quite as long, and extends indeed sometimes to 24 or even 48 hours before all the bubbles are dispersed, and no more alkali is volatilized; or until specimens of the glass exhibit in every respect a fit state for casting. From this time, the fire must be allowed to decline, that the temperature of the glass may fall to the proper degree for casting, and this generally requires 3 or 4 hours.

Casting.—The casting operation takes place in front of the annealing-arch, which is quite distinct from the melting-furnace, and is heated by a separate fire. The sole of this arch must be sufficiently broad to accommodate all the plates which it is to receive, *one by the side of the other*, and must be built in such a manner as to form a level with the surface of the casting-slab or table, Fig. 71. The cast-

Fig. 71.



ing-slab *A A*, composed of bronze, brass, or sometimes of cast-iron, is of longer dimensions than the largest plate, namely, from 10 to 15 feet in length, to half the breadth, and is 6 or 7 inches thick.* (The bronze slab at St. Gobin weighs 50,000 lbs., and cost 100,000 francs =£4000);† the upper surface is true and polished, and moulds the lower surface of the mirror, whilst the upper surface is produced by

* As this slab is strongly heated on the upper surface during casting, and not on the lower, it has a tendency to crack and curve, and this tendency can only be counteracted by considerable thickness.

† We are informed that this slab has now been discarded at St. Gobin, and cast-iron slabs substituted for it.

the motion of the cylinder *B*, and the thickness of the plate (from 4 to 7 lines) is regulated by that of the strips of metal *c c*. Thecy linder is hollow, but thick in metal, and weighs several hundred weights. The casting-plate and its appurtenances are fixed upon a car *E*, which moves upon casters *r*, and is thus capable of being easily placed in front of any particular annealing-arch *V V*.

Fig. 72 represents a plan of the carriage and wheels on which the casting-table of Messrs. Nicholson and Wadsworth is supported; Fig. 73 is a transverse, and Fig. 74 is an end view of the same, with the casting-table *A*. In these figures, *A′* represents a stud or pin, placed vertically in a hole in the cross framing of the carriage, fitting also into a similar hole in the centre of the under side of the table *A*, as seen in Fig. 73. The stud or pin *A′*, is forced up (as the table expands and rises in the process of casting) by a spring coiled round the pin under its shoulder (Fig. 73), and the table is thus kept in its true position, or equidistant at each end of the carriage. The table *A* is

Fig. 72.

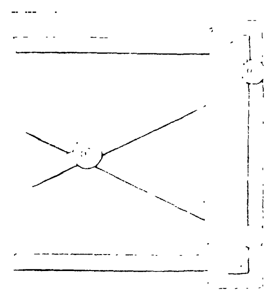
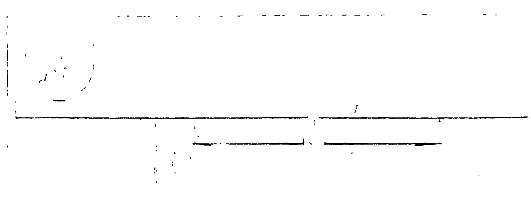


Fig. 73.



supported at the four corners of the carriage by the balls *a*, *a*, *a*, *a*, placed in sockets in each corner of the carriage. The table is thus allowed to expand or contract from its centre without being bound by the frame or brickwork at each end, as is generally the case, and has consequently a lesser tendency to curve on the application of heat in the process of casting. The thickness of the glass, which has generally been regulated by strips of iron placed on the edges of the casting-table for the roller to pass over, is regulated by an annular hoop, or belt of iron, bored and turned to the required thickness, and placed round each end of the roller A^2, as is seen at a^2 in Figs. 73 & 75. This hoop adheres to the roller by its spring or elasticity being divided in a diagonal line, Fig. 75, and by this means the unequal thickness of the plates of glass, generally

Fig. 74.

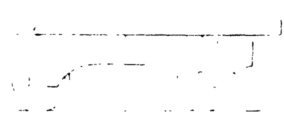
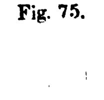


Fig. 75.



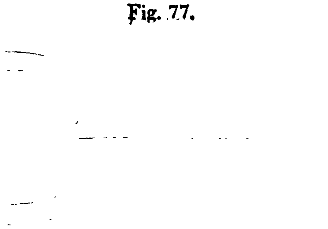
produced by scoriæ or other extraneous matters lodging between the flat strips of iron and the table, is obviated.

Whilst one set of workmen, previous to casting, are employed in warming the casting-slab by sprinkling hot coals over it that the glass may not be too suddenly cooled, others are engaged in removing the charged cuvette from the furnace by means of a large pair of tongs movable upon rollers, and conveying it to the casting-slab, where it is transferred to another pair of tongs, *o o*, Fig. 71, which fit into the groove and is suspended on a crane by means of the chains *b*, and the cross beam *i*.

Fig. 76.

Figs. 76 and 77 represent the elevation and plan of a crane for lifting the cuvettes or cisterns from which the molten glass is poured upon the casting-table. The crane is placed at the end of the table, and farthest from the annealing-kiln. As the molten glass on the cuvette *o*, which is raised by this crane, is distributed across the table before the roller by the vibration of the jib *B*, the curve produced by this vibration is converted into a straight line by an additional or false jib, B^2, sliding on the upper side of the jib *B*; the position or traverse of the false jib B^2 is governed by a cast-iron guide *c*, fixed on the perpendicular shaft of the crane B^1; in this guide there is a slot in which a pulley *f* travels flatwise, the axis of which is connected to the under side of the false jib B^2. Figs. 78 & 79, show the form and position of this pulley in plan and section. By this arrangement the false jib B^2 is forced outwards to its greatest extent, when the cistern is suspended over each edge of the table, and as the cistern, when suspended, is moved across the table *A*, before the roller A^2, it is kept in a straight line parallel to the roller, and distributes the molten glass accordingly.

Fig. 77.



Figs 78 & 79.

The tongs or clasps *M M*, Fig. 77, in which the cuvette is fixed when required to be lifted, are hung and swivelled by two endless chains passing under four small pulleys, *e e*, fixed on the clasps, which chains pass over two larger pulleys, *G*, fixed at each end of a bar, the centre of which is hooked to the crane-chain, Fig. 76.

Suspended in this manner, by the side of the casting-slab, the cuvette is cleansed from all matters attached to the outside, and the

inside is skimmed by a copper blade until the surface of the metal appears perfectly clear; by turning the crane, the cuvette is brought perpendicularly over the casting-plate, which in the meantime has been rendered perfectly clean, after the removal of the hot coals. By inclining the cuvette with the aid of the tongs *o* (Fig. 71), the glass is caused to flow out *in front* of the cylinder, which, in the same moment, is set in motion by the handles *u u*, attached to the axis. In this manner the glass is spread out chiefly in front; it would, however, overflow the sides, if this were not prevented by two workmen applying the iron pieces *x x*, which form a dam at the sides, and necessarily precede the course of the roller. Lastly, to preclude the possibility of the least impurity contaminating the glass, a workman draws the washer *t*, covered with cloth, immediately in front of the fluid glass; this is first withdrawn from the slab, the excess of glass then follows, which pours over the front edge of the plate into a trough filled with water, and, lastly, comes the roller, which remains stationary in the grooves *n n*. Whilst the cuvette is carried back to the furnace to receive a fresh charge of glass from the ladles, the casting is cleared of any redundancy, the thick flange is turned up at *l*, and a rake-shaped iron is applied to it, and by its means the plate is forced forward into the annealing-kiln, where it rests upon a layer of sand. From the time of removing the glass from the furnace, five minutes are only required for this operation, and the casting then remains in the annealing-oven from eight to fourteen days.

Fig. 80.

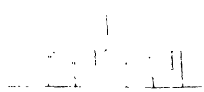


Fig. 81.

Fig. 80, is a front view; Fig. 81, a longitudinal section; Fig. 82, a back view; and Fig. 83, a plan of the annealing-kilns of Messrs. Nicholson and Wadsworth for plate-glass. In these figures, *A* represents the fire-places at each end of the kiln, which are sunk so as to admit of the front one, nearest the opening *B*, being covered by a grating, over which the plate is pushed into the kiln; the aperture into the flue, is shown at *c*. The kilns are sufficiently wide to admit only one plate in breadth, and three or more in length, according to the length of the castings. The doors of these kilns are constructed of wire-gauze, similar to that which is used for Davy-lamps, in place of sheet-iron slides, by which contrivance a more uniform and expeditious reduction of temperature is obtained. The bed of the kiln is prepared of cement, laid in a wet state upon a

Fig. 82.

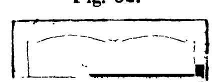
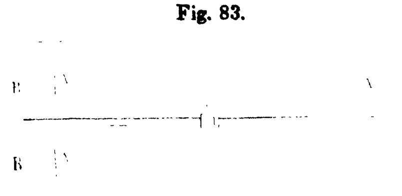


Fig. 83.



stratum of sand, well rammed down, a space of 1½ inches being left between the cement and the walls of the kiln, and wooden pegs are inserted in the wet layer, which, when subsequently burnt away, leave apertures for the escape of steam until the bed is thoroughly dry.

If the plate is too soft on being introduced into the annealing-kiln, it easily sinks in and becomes wavy, which change of form involves a much greater amount of labor in the subsequent polishing process. Even when every precaution is taken, the upper rolled surface is always wavy, though *smooth and polished*, whilst the under surface is *much flatter, but rough*.

Mr. Chance has also proposed the following arrangement for annealing, in which Figs. 84 and 85 represent transverse and longitudinal sections of his kiln. Fig. 86, is a front view, and Fig. 87, a plan in section.

Fig. 84.

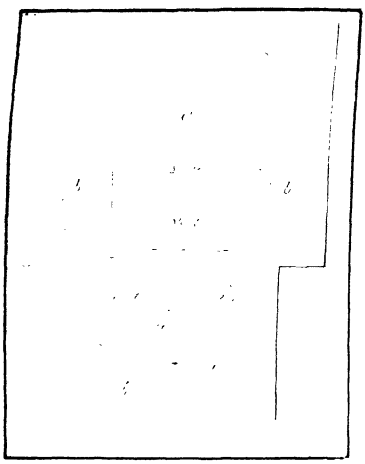


Fig. 85.

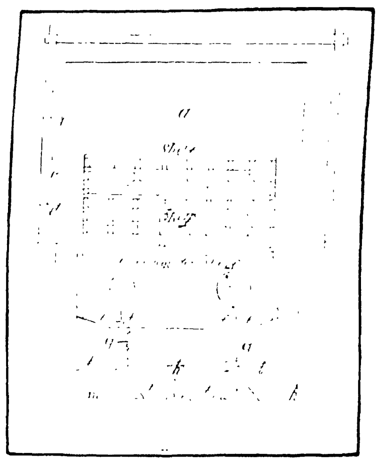
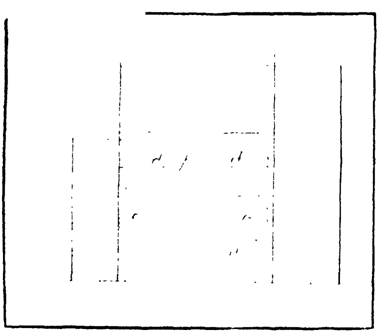


Fig. 86.

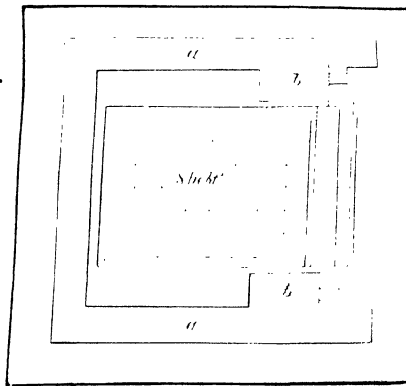


The kiln and shelves are so arranged and constructed, that the shelves on which the plates of glass are placed, may rise and fall, and, when required, can be run out of the kiln on wheels. *a* is the kiln, and *b b* its fire-places for the purpose of heating. The heat and flame rise into the arch, and being reverberated, pass out in front at *c c*. The front of the kiln is made with a large opening, adapted for the passage of the carriage and shelves; but when at work, this large opening is closed by the doors *d*, *d*, except the shaded part *c c*, Fig. 86. This shaded

portion is of course closely luted with bricks and lime when the kiln is cooling down.

The machinery consists of a rectangular frame *e e*, with the wheels *f f* supported on screws *g g*. This frame is raised or lowered by turning the axle or shaft *h*, on which is fixed a screw *i*, which works into, and drives the screw-wheel *j*, on the axis of which is fixed the pinion *k*, which works into, and drives the cog-wheels *l l*, through the centre of each of which there is a female screw, and the wheels *l l* are supported by the bearings *m m*: *n n* are a series of shelves, made of thin stone, or other suitable material, carried by iron beams or rafters, supported at their ends in guides, but not fixed, so that space is allowed them to expand. It is almost unnecessary to say that the shelves must be a convenient distance apart, and that the opening *c* must be arranged with reference to the height of the table or bed on which the plate-glass is cast, so as to render the transference of the plate of glass into the shelves more easy and less liable to accident.

Fig. 87.



In working, the highest shelf is brought down to the level of the opening *c*, and the frame is gradually raised as each shelf receives its plate, until all are filled, when, the opening *c* being luted, the kiln is allowed gradually to cool.

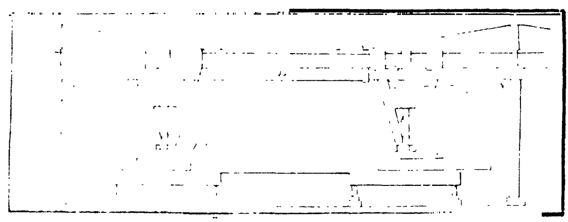
Polishing.—As soon as the plates leave the annealing-oven, and the prominent parts of the edge have been removed, the workmen endeavor, notwithstanding the imperfect transparency of the glass, to pick out such sheets as show imperfections, and by cutting them into pieces to transpose the faulty parts to the sides of the small pieces; this selection being finished, the process of polishing begins.

In this operation two plates are employed, one of larger dimensions, and one 3 or 4 times smaller. The larger plate is imbedded in gypsum in a perfectly horizontal position upon the *grinding-bench*, a table about 2 feet high, resembling a billiard-table; the smaller plate is fixed into the muller, or *upper stone*, a movable box, made heavy by weights, but in such a manner that the plates shall present opposite surfaces to each other, that is, a rough (rolled) towards a smooth (from the casting-plate) surface.* When all is thus prepared, coarse sand and water are applied, and the upper stone is set in motion over the

* Mr. Hartley has proposed the use of a true surface of India-rubber as a bed for the plates of glass to be polished, which, when warm, adheres sufficiently to the glass, and enables it to resist the tendency to shift its position under the action of the muller. Gutta-percha would perhaps answer the same purpose.

whole surface, round its axis, and backwards and forwards at the same time, either by the hand or machinery. When the sand has become too fine, the next size or number is applied, (at Neuhaus, in the Austrian States, seven kinds of sand, of different degrees of fineness, are employed,) and this is continued until the *grinding* is finished, *i. e.*, until the ground plate exhibits a perfectly horizontal and even surface. The same process is then repeated with emery (of which fifteen kinds are used at Neuhaus), instead of sand, until the plate

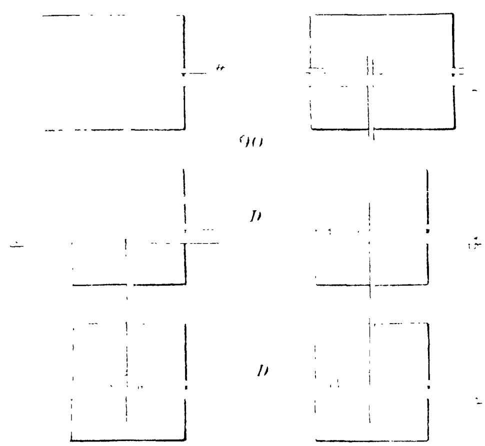
Fig. 88.



becomes smooth as well as even, but is still dull and opaque, and requires polishing to render it transparent.

Fig. 88 shows an elevation, and Fig. 89 a plan of a number of

Figs. 89 & 90.



grinding machines employed by Messrs. Nicholson and Wadsworth for plate-glass, and similar flat surfaces.

In these figures D represents the driving shaft passing above the machinery, and E, the perpendicular shaft, carrying the crank to which the runner or moving surface of glass is attached; the form of the arm or crank is seen separate at Fig. 90; and in this are a series of oblique slots, or openings, for receiving the pin of the runner at different distances from the centre of rotation. The relative position of the grinding-tables will be seen in the plan, Figs. 88 & 89, each

table being supported on three or four adjusting screws, as there represented; in this arrangement of machinery the power is applied direct from the crank to the runner, and thus each separate runner can be stopped or taken out of gear without interfering with the other, by means of the rods and levers *d d d*, seen at Fig. 88, which connect or disconnect the lower bevil on the shaft E, by means of a clutch-box or friction-hoop, as may be required. The sand, or other grinding material (first dried), instead of being distributed by hand, as is usually practiced, is placed in a hopper F, which is supported on a small arm proceeding from the lower end of the upright shaft E, in an opposite direction to that of the crank (as seen in the drawing). This hopper, F, is provided with a small tube, from which the sand or other material is equally distributed on the surface, to be ground or operated upon at each revolution, water being conducted through a small pipe attached to the framing of the machine in any convenient manner. In grinding plates of glass which are too large for the revolution of one of the cranks, an intermediate table is placed between any two of the cranks driven from the same shaft D, which is connected by a horizontal bar, in which the runner is placed and removed from one point to another, as in the arm of an ordinary grinding machine, shown in the dotted lines at G, Fig. 88.

Oxide of iron or crocus, also called colcothar (prepared by roasting green vitriol and washing), is employed for polishing plate-glass. Fig. 91 represents a section of a revolving iron cylinder, employed by Messrs. Nicholson and Wadsworth for calcining sulphate of iron, for the production of colcothar or polishing-powder. To the projecting portion of the axis of the retort *a*, a pulley can be affixed, and by its means a rotary motion can be given to the cylinder, which, at its further extremity, turns in a belt *P*, fixed and secured to the brick-work, and admits of the adaptation of a cap with a funnel to conduct the sulphurous gas into a chamber or flue at *s*. This apparatus is also recommended for the purpose of drying sand for the glass-mixture. The powder is rubbed over the plates by means of a muller, or weighted board covered with woolen cloth. It is obvious that after each of these grinding or polishing operations, the plates must be reversed, in order that both sides may be brought into the same state. In reversing the plates, the greatest care is necessary to imbed them in a perfectly horizontal manner, that both surfaces may remain parallel.

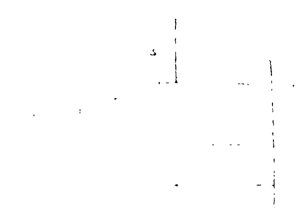


Fig. 91.

Fig. 92, represents a plan, Fig. 93, a side elevation, and Fig. 94, an end elevation of two polishing-frames, as employed by Messrs. Nicholson and Wadsworth, both of which are driven from the same headstock *A*, motion being imparted from the main shaft *B*.

The alternating movement of the longitudinal bars C, and rubbers *d*, in these machines, is produced by the cranks D, D; the rubbers,

Fig. 92.

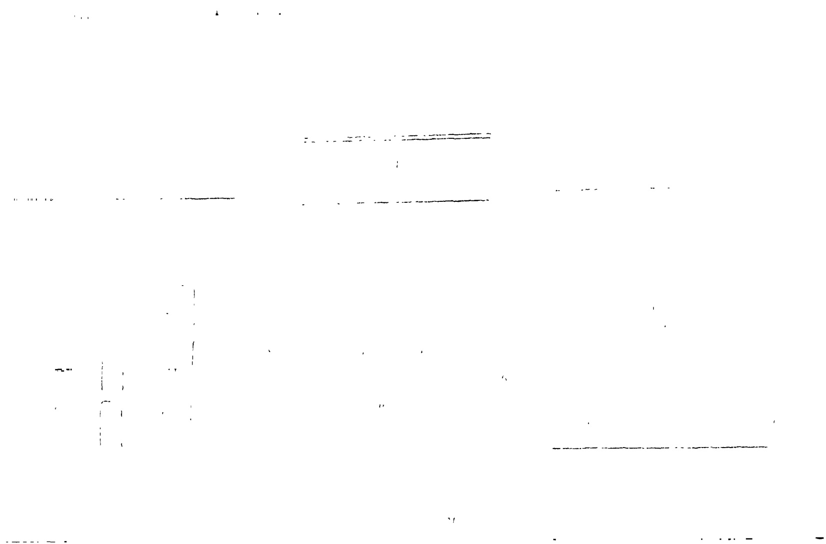


Fig. 93.

marked *d*, being carried by transverse arms attached to the longitudinal bar c, which is supported on friction rollers h^3, at one extremity attached to the end of the frame and between two slides, K, or guides, at the other, as seen at Figs. 92 and 93. The blocks, or rubbers, d, are of cast-iron, hollow on the upper side, with a truly-ground flat surface on the under side, over which the felt is passed, and secured by small bolts to the flanges at each end; and it is found desirable to use two folds of felt on the surface of the rubber, by which means a better surface is produced, less wear experienced in the felt, and less risk of breakage when the fresh lap of the felt wears through. Four blocks, or rubbers, are placed on each transverse bar, as seen at Figs. 93, and 94, which numbers may be increased as required, in a ratio corresponding to the adhesion of the glass to its bed, the same

Fig. 94.

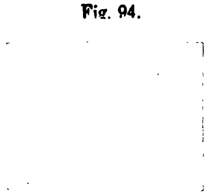
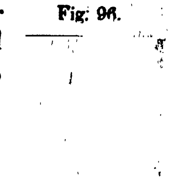


Fig. 95.

being regulated by the size of the plates. The apparatus by which the rubbers are adjusted, as regards their pressure, will be seen in plan and sectional elevation at Figs. 95 and 96, similar to what are at present in use, where E E represents a sliding pin moving freely in the lower part of the small cylinder *e e e e*, while the upper end of the piece E, is pressed by rings of vulcanized caoutchouc or gutta percha E, which are substituted for the spiral spring generally adopted, the amount of pressure being modified by the set screw F, placed on the top of each small cylinder. Beneath the bar C, is an upright lever N, which moves freely on its fulcrum *g*, at its lower extremity (*see* Fig. 93), and passes through a slot, or opening in the bar C, at its upper extremity, so that the alternating motion of the bar C, vibrates the lever N, at each traverse. This lever is provided with strong springs *n n*, either of metal or other suitable material, one placed on each side, which are alternately compressed at the end of each traverse of the bar C, thereby preventing the bar C, overrunning the driving-crank D, and obviating the back lash, so objectionable in ordinary polishing machinery. On the axis of the intermediate wheel, between the driving-wheel and those on the shafts which carry the cranks D D, is placed a bevil-wheel H, which gears into another bevil on the transverse shaft *h h*. This shaft, *h*, *h*, is connected or disconnected by a coupling or clutch-box and friction-hoop, to the shaft h^2, passing under the frame and traversing-table I (*see* Fig. 93), the position of the coupling or clutch-box being governed by the lever h^1. Supposing the coupling to be closed, and the shafts *h* and h^2 connected, the bevels *i* and i^1 (placed on the shaft h^2), will convey motion to the two upright shafts i^2, on the upper end of which are placed two cranks L, as best seen at Fig. 92 on the left-hand side of the headstock A, where the table I, is removed for the purpose of showing this improvement. These cranks L, receiving a slow revolution, are connected with the under side of the table I, by the connecting-rods M, M, so that each revolution of the cranks L, L, traverses the table I, in a line at right angles to the bar C, the table I, being guided by slides at the edges and traversing on planed edges (*see* Fig. 93), similar to those used in planing machinery, and other traverse motions. By this arrangement of machinery it will he seen that the rubbing traverse of the bar C, being always in one direct line while the machine is in motion, and the transverse traverse of the table I, always varying in speed according to the position of the revolving cranks L, each point of the surface to be polished is brought under the rubbers for a different duration or period of time at each traverse of the table I; or, in other words, the diagonal line formed on the surface to be polished by the compound movement of the bar C, and the table I, is never twice alike in succession, and thus many traverses of the table must take place before the rubber passes over precisely the same line on the surface to be polished, while every

Fig: 96.



part is submitted to the action of the rubbers, and a more close approximation to perfection in a polishing-machine is thus obtained.

Another modification of this series of improvements is represented at Figs. 97 and 98, in which the movement of the table I, is the same as that already described; but, instead of the blocks or rubbers *d*, rotary rubbing-surfaces are substituted, marked Q, which are placed on parallel shafts, and receive a rotary movement by means of the bevel-wheel d^2, driven by similar bevels cast on a hollow shaft d^3. Through the centre of the hollow shaft d^3, is passed a shaft provided with a midfeather, or projection, which carries the hollow shaft d^3, in its rotation, at the same time that it permits it to slide or traverse along with the carriage *e*, *e*, *e*, *e*, in which the shafts and circular rubber Q, are supported. The rotation of the shaft d^3, proceeds from the shaft *h*, below, through spur gearing, as seen at Fig. 97; the spur-wheel h^1, being keyed on the shaft with the midfeather, as already described. To produce an opposite rotation on each shaft on which the circular rubbers Q, are placed, the small bevels d^2, are reversed, so that they keep in gear at each part of the traverse of the carriage *e*, *e*, *e*, *e*, carrying the hollow shaft d^3, along with the carriage, as seen in the drawing. A slow traverse of the rotary rubbers Q, in the carriage *e*, *e*, *e*, *e*, is effected by the lever e^1, which moves on its fulcrum at the lower end, having its upper end connected with the carriage *e*, *e*, *e*, *e*. This lever e^1, is connected by the rod e^2, to an eccentric, or crank, placed on the lower end of the same shaft which carries one of the cranks L, so that a slow vibration is imparted to the lever e^1, which traverses the carriage *e*, *e*, *e*, *e*, and revolving rubber Q, which traverse, in combination with the traverse of the table I, as already described, produces the varying diagonal line on the surface to be polished, as already described in the former polishing-machine. Referring to Fig. 92, the dotted lines *x*, represent an arrangement for prolonging the shaft which carries the crank D, so as to apply a second machine to the same headstock A, the crank M^1, being at right angles to the crank D, and the centre line of the second machine in the direction of the dotted line *m*. By this arrangement the rubbers of both machines can be arranged to act together while the transverse traverse of the additional table will be gained by connecting it with that of the adjoining machine. By this arrangement four polishing-frames would be driven from one headstock; but where only two machines are driven from one headstock, as first described, the space between the adjoining

Fig. 97.

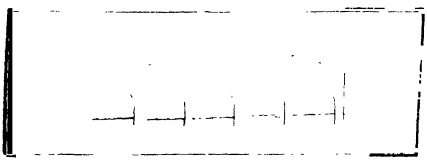
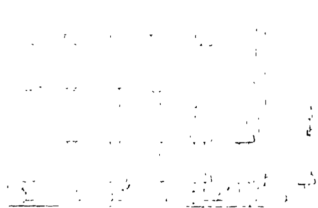


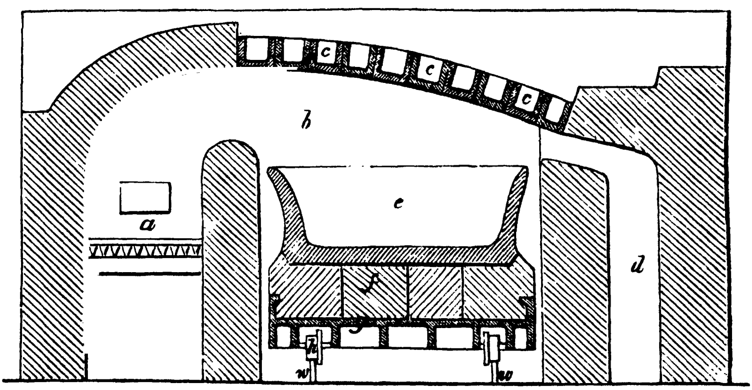
Fig. 98.



pair of machines needs only be sufficient for a man to pass on the one side, as represented at Fig. 92, where the outline of a second pair of polishing-frames is seen above; but on the opposite side of each pair of machines a space is left sufficient for the removal of the slate-frames and similar work, which space serves for two pair of four machines. Thus, the machines stand in groups of four, which diminishes the labor of the operators in charge of the machines, and enables them to examine the work in progress with greater facility than in the arrangement of machines as ordinarily placed.

Mr. Bessemer has lately proposed a new method of casting plate-glass in sheets, by pouring the glass in the melted state directly from the pots between two rollers, placed at a certain distance from each other, so as to ensure a uniform thickness throughout. The pot-furnace and machinery for this process are entirely novel and very different from those in common use, and as the invention is likely to be carried out in practice, a notice of the most important parts of his patent will not here be out of place. The furnace employed is a reverberatory furnace, Fig. 99, with a low arch and descending flue *d*. The

Fig. 99.



flame proceeding from the grate *a*, plays upon the surface of the materials in the pot *e*, in the fire-space *b*. The arch is formed at that part which is most exposed to the heat, and the alkaline vapors from the mixture, of hollow bricks *c c c*, over which a draught of cold air is caused to play, by connecting the space above the furnace with the ascending main chimney. The object of this cooling, which is of course attended with a loss of heat, is to prevent tears, consisting of the fusible product of the action of the alkaline vapors upon the ingredients of the bricks, from forming on the arch, and falling into the glass during fusion. The pot *e*, is of very large dimensions, as large indeed at the lip on the one side as the width of the plates, which it is proposed to cast with it. It is set upon a siege composed of large masses of fire-stone, and these are cemented together, as well as the pot upon them, by some bottle-glass, which, in the fused state, enters

the crevices and binds the whole firmly together upon the strong-ribbed cast-iron frame *g*.

This frame moves upon four wheels *h*, upon a railway *w*, which extends beyond the furnace to the rolling-machinery, to be described immediately. Thus, pot, siege, and frame are all wheeled in and out of the furnace at once, as will be seen by reference to the section, Fig. 100, where *j j* represent the hollow bricks, or masses of stone, by the removal of which a free ingress and egress is allowed the whole carriage on the continuation of the rail *w*. The pot and carriage fill the entire recess of the furnace, and the flame playing upon the top does not much affect the iron frame of the carriage through the bad conducting stones which form the bed of the pot. Fig. 101 is a longitudinal section through the middle of the frame-work and machinery, by means of which the pot and siege are raised, and the melted glass poured out between the rollers *o*, *P*. These rollers can be removed to a greater or lesser distance from each other, and thus the thickness of the glass to be rolled can be regulated. The axis of the roller *P*,

Fig. 100.

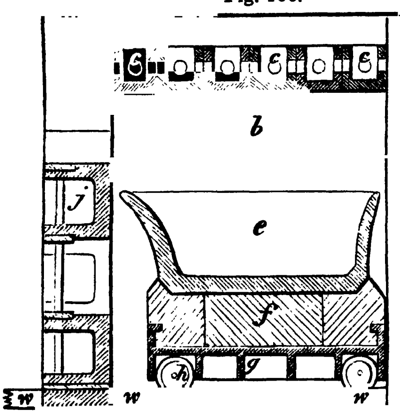
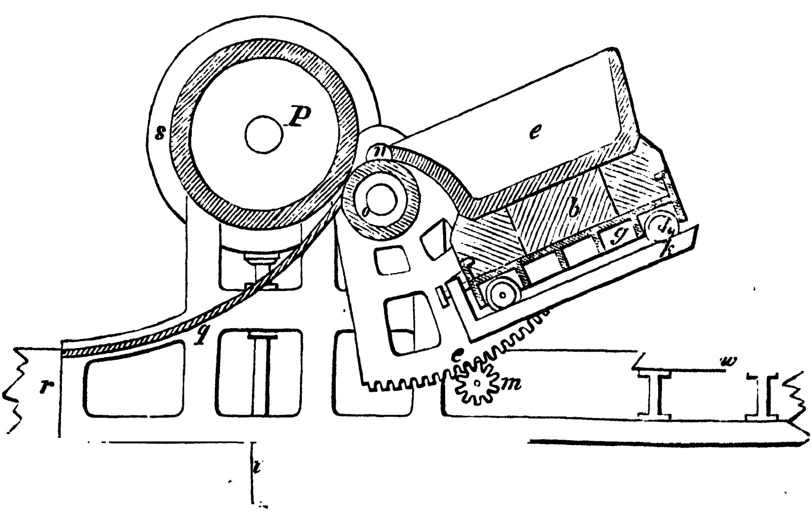


Fig. 101.



has a large bevel-wheel *s*, on the outside of the framing, which is driven by a pinion on the end of an upright shaft *t*, which proceeds from below the floor, and is driven by an underlying shaft from a steam-engine, or other motive power. The siege and pot with the melted glass, being removed from the furnace on the railway *w*, is fixed upon the continuation of the railway *k*, which forms part of the tilting-frame *e k n*. This tilting-frame occupies nearly the whole of the space between the outer framing, which supports the rollers, and can be raised through a segment of a circle by means of the rack-work *e*, and the pinion *m*, upon the centre *n*. The rollers, whilst employed in rolling the glass, are kept cool by a current of water passing through them from a pipe which works in a stuffing box, so as not to impede the revolution of the rollers. A strong curved plate *q*, extends the entire width between the outer frames, fitting closely to the roller *o*, and is secured to the frames by lugs; on this plate the sheet of hot glass, as it issues from between the rollers, slides down to a flat table *r*. The roller *P*, is furnished with a rib throughout its whole length, which cuts the sheets of glass, as they pass through, into lengths. In a subsequent specification the inventor appends two other *finishing-rollers* to the machinery; and these are situated rather below the two *forming-rollers*, and, being placed rather closer together with an accelerated motion, they render the glass more smooth and flat. A fluted or checkered surface can also be given to the sheet by means of either pair of rollers; and it is found desirable to indent or roughen the forming-rollers, that they may gain more hold upon the glass, and not be subject to revolve without taking the glass with them. The checkered surface of the sheets facilitates also the subsequent polishing process, by retaining the grains of sand or emery for a longer period in contact with the sheet.

Bessemer proposes to heat the annealing-kilns for all kinds of glass, by a current of hot air obtained from a chamber situated between the furnace where the glass is melted, and the chimney, this chamber being filled with cast-iron pipes, through which the air is caused to pass by suitable blowing-machines, and is conducted from these pipes to the annealing-kilns. A saving of fuel is thus effected, the articles to be annealed are not subject to injury from the dust and products of combustion of the fuel, and the heat is more easily regulated by a proportionate admission or exclusion of hot air.

The method of polishing proposed by the same inventor, consists in laying the plate of glass upon a slab of slate, placed perfectly horizontal upon a bed of brick-work, and causing an endless belt, or strap, composed of gutta percha, and covered with felt and polishing material, to pass in contact rapidly over the surface of the glass, and to traverse slowly across it in a direction at right angles to the line in which the belt moves over the drums that impel it. The belt is of the same length as the sheet to be polished, and is pressed upon the entire surface of the glass by a number of small rollers, which rest their whole weight upon it. The whole length of the sheet of glass is thus rubbed at once by the belt, and the slow transverse motion of

the belt, this latter not being necessarily of the same width as the sheet, brings in succession every portion of the sheet in contact with the polishing-surface. The continuous action in one direction of the strap, renders it unnecessary to cement the glass to the table, as one end of the plate being kept in contact with a raised rib or stop let into the table, effectually prevents it from shifting its position.

The more a mirror-plate is injured by the operation of placing it in the annealing-kiln, and the more wavy its rolled surface, the greater is the difficulty of grinding and polishing it. With a view to obviate these two evils, an attempt has been recently made to press the plates between two metallic slabs, without the use of a cylinder, and the soles of the annealing-kiln have been constructed in a circular form, perfectly even, however, and capable of revolving; as soon as a plate has been introduced at the mouth of the kiln, it can, by this means, be set on one side by simply turning the sole of the kiln, and thus room allowed for the insertion of another plate. In this case, the plates must be removed from the kiln in the same order in which they were inserted.

By means of a steam hammer, hydraulic press, or rollers arranged between two furnaces, the one of which is similar to those used for flattening glass, and the other to an annealing-kiln, small plates of plate-glass can be subjected to compression, so as to increase their area, and flute or checker them on the surface.

The amount of time and labor expended during the polishing of plate-glass, may be estimated from the fact that the plates are reduced one-third, or even sometimes one-half in thickness. As the faults are only made apparent by the polishing, and the internal structure and purity of the glass are then first seen; a second very careful selection is now made of the plates, and such as must be cut up into smaller plates, or re-polished, are separated, whilst the others are now ready to be *silvered* or coated with amalgam.

This operation is commenced by spreading a leaf of tin foil, which must be of somewhat larger dimensions than the plate to be silvered, upon the silvering-table and brushing mercury over it. When the metallic surface is uniformly covered, a small quantity of quicksilver is added, so that it attains a height of two or three lines; the gray coating of oxide is then removed with a wooden rod, and a brilliant surface produced. The plate of glass may now be placed upon it; if this, however, were allowed to drop down in a perpendicular manner, dust and air would certainly be enclosed between it and the metal; for this reason, the plate is pushed slowly forward from the side, with the longest edge foremost, and this must always dip below the surface of the mercury. The pure metal alone is thus brought into contact with the glass, and a brilliant surface is produced. The plate is now floating on a bed of quicksilver, at the bottom of which lies the amalgamated sheet of tin foil. When, therefore, the mirror is loaded with weights, and the table is inclined at an angle of 10° or 12°, the excess of quicksilver flows away. The removal of the last portions of quicksilver, and the drying of the amalgam, is effected by placing the plate

in an upright position. Three or four weeks are requisite for completing the coating upon a large mirror.

The operation of coating glass with mercury is attended with serious detriment to the health of the workmen from the vapors of the mercury; it also requires very considerable time for completion, and is subject to frequent miscarriage. The plates often break under the pressure of the weights with which it is necessary to load them; drops of mercury sometimes flow down and carry the amalgam with them, when the silvered mirrors stand on end, giving rise to curved streaks (worms), and the amalgam is liable to spoil by crystallization or carriage. The process for silvering mirrors, proposed by Drayton, and tested by Faraday and Warington, is free from all these defects. The silvering fluid is obtained by mixing ammonia with nitrate of silver, filtering the mixture and adding to it an alcoholic solution of oil of cassia.* This fluid has the property of depositing bright metallic silver, on the addition of the *reducing-liquid*, which consists of a solution of 1 part oil of cloves (*ol. caryophyllorum*) in 3 parts alcohol.† In order to silver a mirror by this process, a perfectly clean plate of glass is surrounded by a rim of putty, and a layer of silvering fluid, one or two lines in depth, is poured upon it. As soon as the solution of oil of cloves is added, a film of brilliant metallic silver attaches itself firmly to the surface of the glass, and this takes place with a rapidity proportioned to the quantity of the solution that is used. The coating succeeds best when the reduction proceeds slowly, and is produced by a very few drops of the solution; from 6 to 12 drops are sufficient to cause the precipitation of 4½ ounces of the solution of silver, and the film of metal is so thin that a square foot of it only weighs from 12 to 18 grains; in fact, the value of the silver covering a surface of 10 by 5 feet, varying from $\frac{1}{2500}$ to $\frac{1}{1700}$ of a line in thickness, does not exceed from 7 to 10 shillings. It is obvious that the principle of the process consists in deoxidizing the oxide of silver by means of the volatile oil, and this is effected *without any evolution of gas* which might destroy the continuity of the metallic surface. The nitric acid remains in combination with the ammonia.

Notwithstanding the apparent advantages of this process, it has not been carried out extensively by the manufacturers of mirrors into whose hands the process has been transferred, and this is probably due to the difficulty of obtaining a perfectly clear, unspotted surface of any considerable extent. It is also probable that the darker color of the coating is considered a disadvantage by the public.

LEAD OR FLINT-GLASS (CRYSTAL).

The discovery of lead-glass is of English origin, and its production arose from very different reasons from those which render it at present

* One ounce of nitrate of silver, 3 ounces of alcohol of 87 per cent., and 20 to 30 drops of oil of cassia, form the mixture.

† Formic or aldehydic acid might perhaps be conveniently substituted for this mixture.

so extensive a branch of manufacture. It was necessary, in using coal as fuel, in the manufacture of white glass, to protect the metal from the smoke and soot of the flame, which colored the glass. This was the origin of the use of covered pots, which very much impede the fusion, as compared with the open pots that are employed in furnaces, heated by the smokeless flame of dried wood. An attempt was, therefore, made to render the mixture of ingredients more readily fusible; if this, however, had been effected by the use of a larger quantity of alkali, the glass would be too easily decomposed, and recourse was consequently had to oxide of lead; the result soon showed the remarkable properties exhibited by glass thus prepared with reference to light. Lead-glass has since been made in consequence of its high refractive power, and the process for preparing it was soon introduced into other countries.

FLINT* GLASS, OR CRYSTAL.

Lead-glass is peculiarly adapted for articles of luxury, such as goblets, chandeliers, decanters, &c., from the ease with which it is ground or cut, from its brilliant lustre, high refracting power and perfect freedom from color. The mass which is used for this purpose is called, in a more limited sense of the word, crystal (from its resemblance to rock crystal), and it excels the Bohemian grinding-glass (crown-glass) with reference to refractive power and easy fusibility, although the latter is harder and more completely colorless. When once the nature of lead-glass was known, it was easy to establish the proportions essential to its good quality. Silicate of lead communicates a distinct yellow color to glass when it preponderates over the alkaline silicate in the composition beyond a certain limit; and the peculiar bluish-green tint of silicate of soda becomes much more prominent in the combination as it exists in lead-glass. As nearly all the articles composed of flint-glass, or crystal, require to be ground, in order to exhibit their greatest brilliancy, they must be constructed in a very massive form; there is consequently more necessity for avoiding all sources of color, and for preparing the glass from oxide of lead, potash, and silica alone, observing, at the same time, certain limits in the proportions of these ingredients. From the analysis cited at page 25, it will be seen that the composition of crystal (after deduct- the extraneous constituents) may be expressed by the following formulæ:

I. $KaO,2SiO_3+2(PbO,2SiO_3)$.
II. $3(KO,3SiO_3)+4(PbO,3SiO_3)$.
III. $2(KO,2SiO_3)+3(PbO,2SiO_3)$.
IV. $3(KO,2SiO_3)+3(PbO,2SiO_3)$.
V. $KO,2SiO_3+PbO,2SiO_3$.

* So called because flint was first employed in the manufacture as the source of silica.

In one case, therefore, triple silicates are the proximate constituents of the glass; in the others, double silicates.

The mixture is composed of sand perfectly free from iron, pure minium, and purified potashes, in the proportions of about 3 : 2 : 1; more silica, however, is employed when the composition is fused in open pots, with wood fuel, and *vice versâ*. *i. e.*

	WITH COAL AS FUEL.	WITH WOOD AS FUEL. ACCORDING TO BASTENAIRE.*
Sand, washed and calcined	100 lbs.	100 lbs.
Minium	70 "	45 "
Purified potashes	30 "	35 "
Cullet, or broken glass.		

In addition to these, saltpetre or arsenic is used as a discolorizing material. Common peroxide of manganese, varying in its nature, sometimes produces an amethystine color in the glass, and is always injurious from the iron which it contains; this has induced manufacturers to employ only the very purest pyrolusite or purified peroxide, on the composition of which they can depend. The minium affords the oxide of lead to the glass, and exerts, at the same time, a discolorizing action, by parting with oxygen at a red heat, previous to the fusion of the glass, and thus destroying much brown empyreumatic matter contained in the potashes. With a like object in view, 10 to 20 per cent. of the potashes is often replaced by saltpetre, when the price admits of its application; this salt is at once a pure and a purifying material.

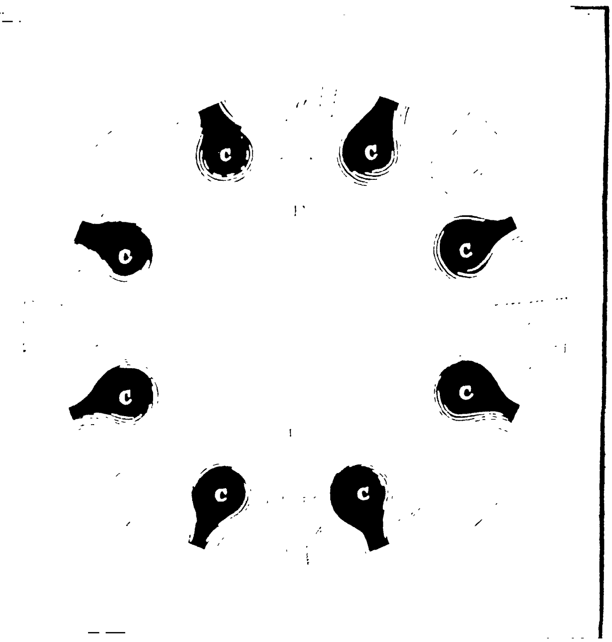
The fusion occupies six or eight hours, and the fining, which is very much facilitated by the easy fusibility and the purity of the materials, requires about the same time.* This process is frequently carried on in two separate vessels on the Continent of Europe, as was the case with plate-glass; the melted metal is then scooped or ladled from the fusing-pots into the clearing-vessels. The superior quality of the glass is thus obtained at considerable cost of fuel; to melt 8 cwts. of glass in the ordinary manner, 40 cwts. of wood are necessary; when the ladling process is carried out, 59 cwts. are consumed.

During working, the glass must be protected from the smoke of the furnace, and iron must not be brought into contact with it, as it otherwise infallibly becomes of a dark-brown color. Iron is dissolved by the glass, taking the place of the lead, which separates as metal in the most minute state of division; the color is therefore produced by both, by the iron dissolved, and by the precipitated metal; the solid particles of soot also blacken the glass by attaching themselves firmly to its surface; to prevent these effects, the re-heating is carried on under the protection of the pot-covering or hood, shown in Fig. 3, page 36, and the metal is not exposed to the flame of the furnace.

* In England it is customary to begin the "found" on Friday night, and the glass is then fine and fit to work on Monday morning, when the men begin to work, and continue till Friday afternoon. The goods made on Thursday and Friday are generally of inferior quality to those made in the earlier part of the week.

The construction of furnaces and melting-pots in manufacturing flint-glass, are somewhat different from those employed in the other descriptions of glass. Fig. 102, is a ground plan of the melting-fur-

Fig. 102.



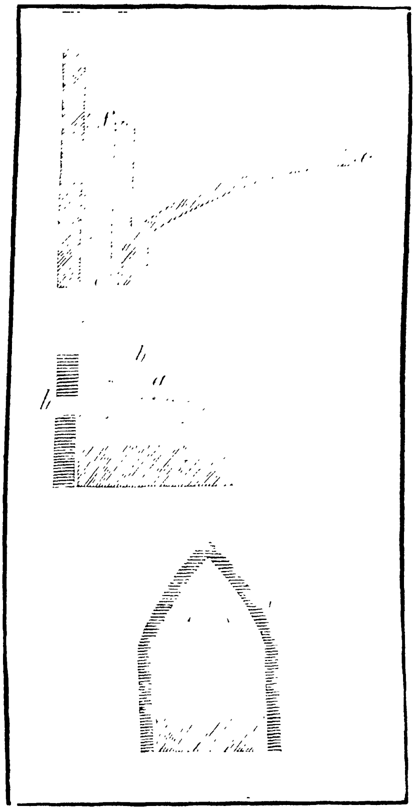
nace; *C C C* are the post, which are situated at equal distances between the pillars or piers *E E*, which support the exterior dome. *a a* are the openings in two of the piers for charging with fuel. Fig. 103, is designed to show how the heat is carried round the pot in its exit from the furnace. The pots are covered with a hood-shaped top, as shown in Fig. 3, page 36, and these fit the working holes of the furnace, so that the smoke and heat cannot escape in the same way as in the usual glass-furnaces; *a* is the pot with the top *b*; *c* is the roof of the furnace; *d*, the "siege" on which the pots are placed; and *e e* a flue, low down, which passes between the furnace and the cone till it reaches a point *f*, where it enters the cone itself; *g* is a front view of the pot and arch of the cone, which allows the workman to approach the opening in the furnace, against which the mouth of the pot is placed; *h*, is an opening direct from the outside into the flue for the purpose of keeping it clean. Fig. 104 is a general view of the melting-furnace, cone, and working-holes.

It consists of two domes *A A*, *B B*, one within the other, of which the interior one is flat, and the exterior of considerable altitude, terminating in a high chimney. The only connection between the domes is by the flues *G G*, which are situated one on each side of the crucibles, so that they receive the whole body of the flame as it

passes from the fire-place to the exterior dome, and thence to the chimney.

Flint-glass is either formed by simple blowing with the pipe; by blowing in moulds, or by moulds alone, in every case the form can be improved—as is generally done—by grinding, &c.

Fig. 103.



The moulds are carefully constructed of brass or iron, and are somewhat wider at the upper part, when of simple construction, that the pieces may be easily removed, or are composed of more than one piece when projecting parts are to be moulded. A mould of the latter description is represented in Fig. 105, intended for a decanter; a section of the mould is shown in Fig. 106. The bottom *e*, and the sides *a*, of the body, form the lower and larger part of the mould, and are held together by the screws *b b*; the upper smaller part consists of two halves, meeting in the line *z z*, which open after the fashion of a pair of tongs when turned upon the hinge *d*. That they may not be extended more than is necessary, the two wings are impeded by the plugs *o*, fixed to the ring *i*. The workman introduces the glass globe *g*, attached to the pipe, into the body of the mould, the neck portion being thrown open, and blows with great force into the globe, as soon as the neck portion has been closed by an attendant, and fixed by the screw *m* (the female screw belonging to which projects at *n*). The glass is now forced, by the pressure, against the sides of the mould, and extends in the form of a cap at *g*, above the margin, where the pipe is detached in the direction of *x x*. The cylinder *h*, and another similar one, more at the back, are intended for the insertion of wooden handles.

[The folding together of the parts of a mould for glass, necessarily leaves what is called a mould-mark on that part of the glass against which the joint comes; and when the part thus marked is horizontal the eye very readily detects the line. Thus the flat foot of a wine-glass, or other goblet-shaped glass, when moulded with an opening or divided mould, exhibits distinct lines on the upper surface of the

Fig. 104.

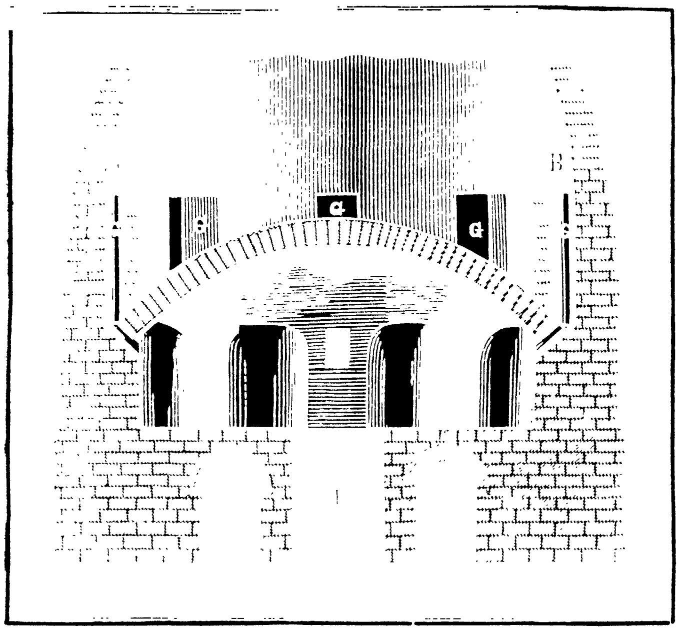


Fig. 105.

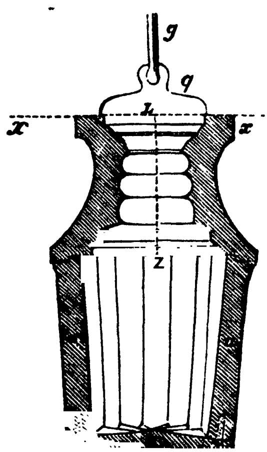
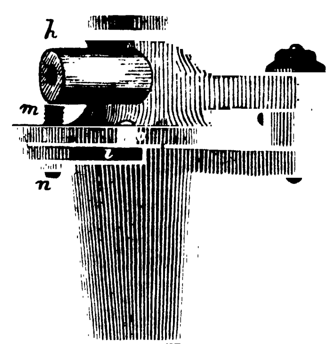


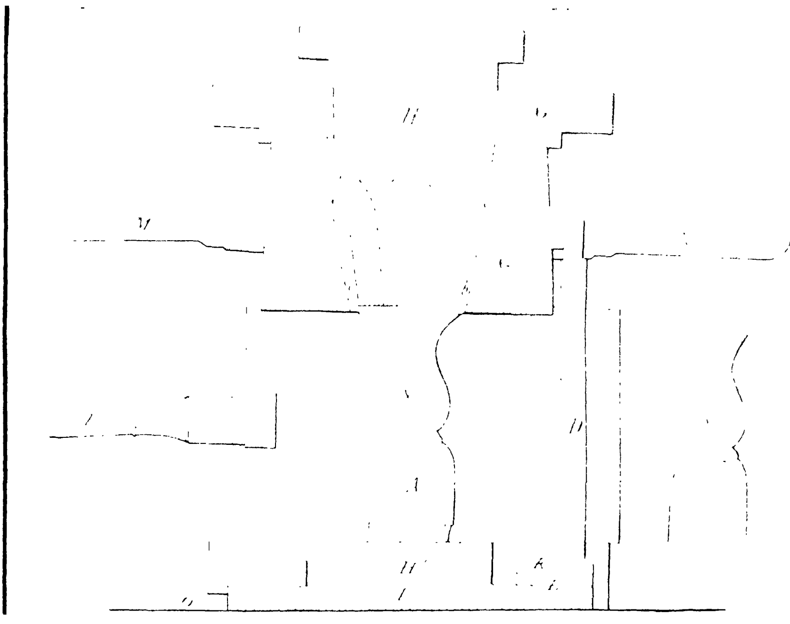
Fig. 106.



foot. In order to remedy this defect, and at the same time to cast the body of the glass in an undivided mould, Mr. Joseph Magoun, of Massachusetts, in 1847 invented an ingenious form of mould which is represented in vertical and longitudinal section in Fig. 107, where *A* represents the core of the foot of the glass first cast in a cylindrical or cup-shaped form, to be afterwards opened out in the form of a disc. *B* is one-half of the shell which surrounds and forms the shank, *X*,

of the glass; *D* is the hinge connecting the two parts of the shell together. *E* is one of two handles which serve to turn the two parts of the shell round the hinge *D*, when the glass is to be taken out,*

Fig. 107.

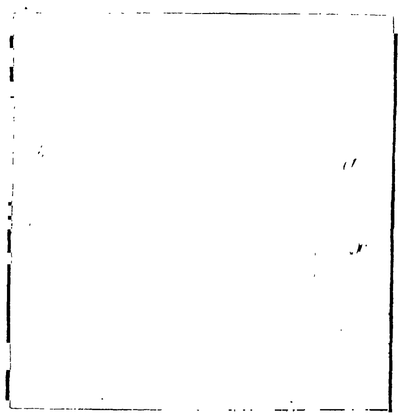


after being pressed. *G* is a cylinder of metal having a central portion excavated to form the body of the wine-glass, and a hole quite through the lower part, by which the shank, and cylindrical bottom may be driven up and removed, thus dispensing with any opening in that part of the mould which forms the body, and of course not leaving any mould marks on that part of the glass. *H'* is a cylindrical seat for the foot core *A*, and this seat is attached to the camplate *I*, which is capable of receiving a horizontal movement by means of a handle *O*. *I'* is a cam on the camplate *I*, and *K* a corresponding counter-cam which, by the horizontal movement of *I*, elevates or depresses *A*. *a b* represent the lower part of the body of the glass while in the mould; *c d*, the cylindrical or cup-shaped bottom. *Y* is a section of the whole shank and cup-shaped bottom, the latter to be opened into a disc, by heating at the work-hole of the furnace, and expanding in the usual mode of working, whereby the mould marks are obliterated and the glass brought into the required shape. The purpose of elevating and depressing *A*, is to detach the core from the glass after it is pressed, and thereby to enable it to be drawn up through the undivided part of the mould *G*. *H* is the core which is forced downwards to form the main or upper cavity of the wine-glass;

and G is a top ring through which H works, and which rests on the top of the undivided mould G.

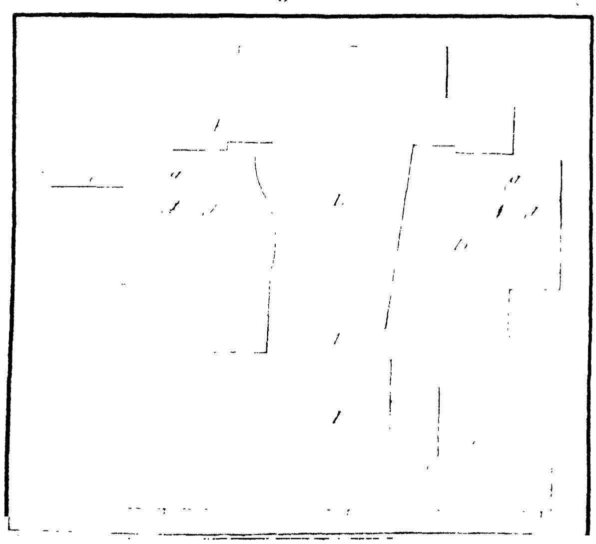
In 1848 Mr. Magoun invented and patented another press-mould intended more particularly for tumblers, and similar articles, in which it is desirable to produce indentations or cavities, *a*, *a*, *b*, Fig. 108, and which, if produced by the projecting parts of an undivided mould, would entirely prevent the drawing out of the finished article, as it is evident that the prominent parts *x y*, could not pass out by the projections *a* and *b* of the mould.

Fig. 108.



To effect this purpose he constructs his mould as seen in vertical section in Fig. 109, where *L* represents the main core forming the interior of the tumbler; *K*, the ring which directs the movement of the core; *g*, *g*, is a ring having a handle *e*, by means of which a partial revolution in a horizontal direction may be given to it, by which the cam *f*, on its lower side, may be made to

Fig. 109.



act in the groove *d*, of the sliding square pistons *B*, *D*, by which they are thrown inward towards the core *L*, when the glass is being pressed and drawn outwards, when the tumbler is to be removed. *I* is a

cylindrical piston projecting upwards a short distance into the bottom of the tumbler, forming a smooth cavity therein, and intended to elevate the finished article so that it can easily be withdrawn by the top. This elevation of *I* takes place by means of a partial revolution given to the bottom plate *P*, carrying round cams *m* and *n*, which, acting on tongues *t*, raise *I* high enough to force out the tumbler.]

Massive pieces, such as plates, are formed by pouring melted glass between two plates of metal composing the mould, and the excess of glass is squeezed out from the crevices, by applying weights to the mould.

All articles of flint-glass, whether blown or moulded, require annealing previous to cutting or grinding, and as they are frequently constructed of very different thickness, two kilns, which can be heated to different temperatures, are requisite; the larger and thicker pieces require that the kiln should be much hotter than is necessary

Fig. 110.

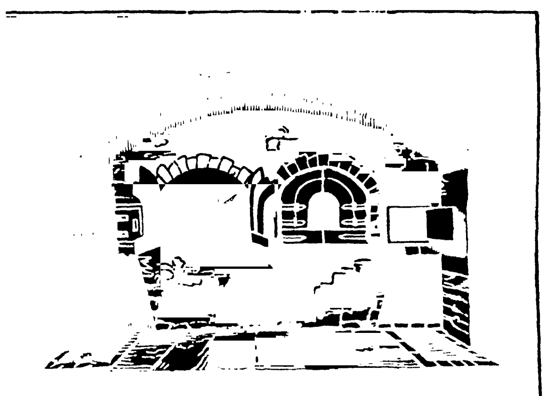
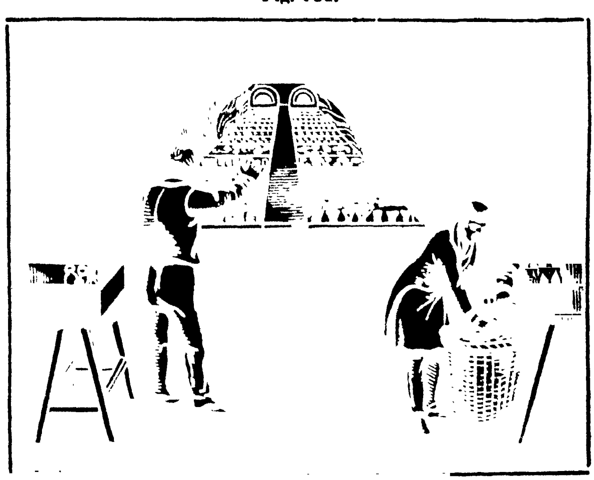
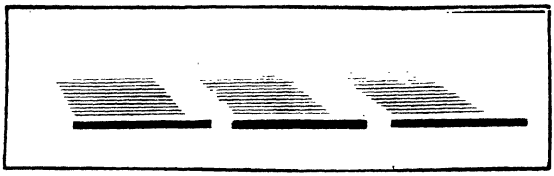


Fig. 111.



for thinner pieces. These kilns are long, low buildings, arched over on the top, as shown in Figs. 110 and 111, the fire-place is shown at the side. The various articles are all placed on sheet-iron trays, Fig. 112. These trays are put into the kiln, through the opening in front,

Fig. 112.



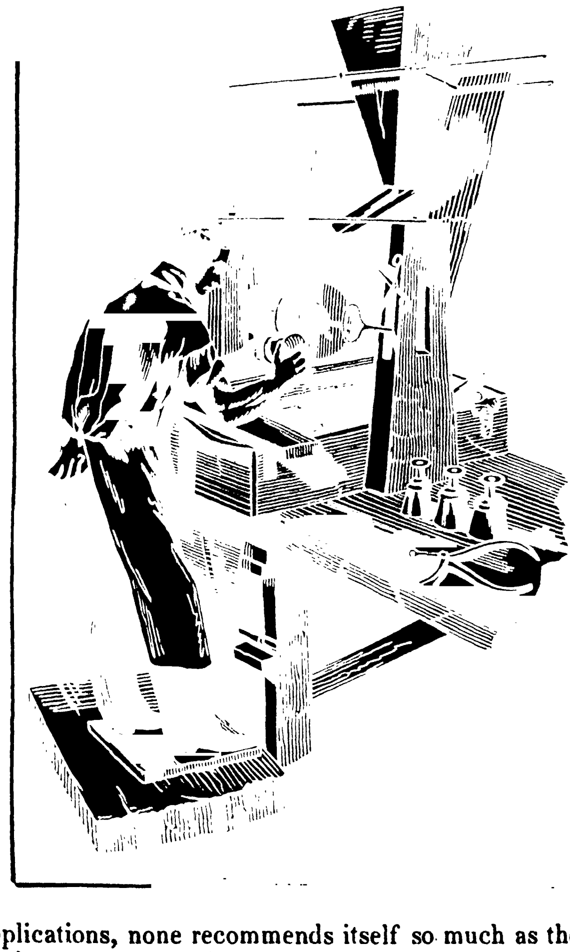
and are all connected together by hooks, by which means they can be moved by a chain, worked by windlass or similar machinery, to the further end of the kiln, and are thus gradually withdrawn from the hottest part, and, having arrived at the further extremity, are removed at a temperature little above that of the atmosphere.

Moulded glass never exhibits its full amount of lustre, nor even the degree of sharpness of the metallic mould; the glass, which is never limpid in its liquid state, is first cooled by contact with the metallic surface, and is thus prevented penetrating into the sharp corners of the mould, nor does it even accommodate itself perfectly to the flat sides. For this reason, the surface of moulded glass is not even, but always more or less curved, and the edges are not sharp; these properties are more marked in Bohemian, and less in flint-glass. Moulded pieces can consequently never be compared with cut glass; but the use of moulds as a preparatory step to grinding, is of great advantage to the grinder, as the vessel acquires a perfectly regular form, and, although in a crude state, presents all the prominent and receding facets to be perfected at the lathe.

The ordinary utensils used in *grinding* or *cutting* glass, are discs of iron, sandstone, or copper, which revolve in a kind of *lathe*, (Fig. 113); their edges, which are sharp, angular, or rounded, are supplied with sand for *rough grinding*, and with emery for *fine grinding*. Similar discs of tin, wood, or cork, used with pumice-stone or colcothar, are employed for polishing the glass. It is obvious that not only discs with very different edges will be required, but also discs of very different dimensions, from 8 to 10 inches in diameter ($\frac{1}{2}$ to $\frac{3}{4}$ of an inch in thickness). For inscribing initials, coats of arms, designs, &c., discs of copper of the size of a halfpenny are employed, with oil and emery; the finest incisions are made with copper pencils, either pointed or ending in a button or small disc. The mode in which these are applied will be evident by reference to the wood-cut Fig. 114. The hard grains of the polishing material penetrate the mass of the soft metal during the process, and form a species of file, which, in revolving, cuts into the softer glass.

The removal of the oppressive excise laws, in England, has given a most extraordinary stimulus to the glass trade, and among many

Fig. 113.



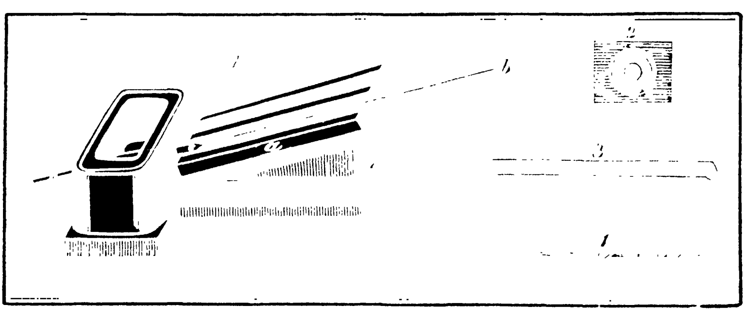
novel applications, none recommends itself so much as the manufacture of pipes or tubes. We may refer to a cheap process which Messrs. Chapman and Gray have proposed for this purpose. Another proposal, patented, in England, by Mr. Roe, also deserves some notice in this place.

Fig. 115, 1, represents a general view of Mr. Roe's apparatus, and Fig. 115, 2, a front view of the same. *A* is a vessel constructed of clay, through which a tubular metal mandril (shown in section at 3) passes from back to front, the back orifice being fitted close round it. The front orifice *a* is left open, while the mandril is so supported by suitable bearings at the back, that it occupies the centre without touching the sides, and leaves a space for the liquid glass to flow round it. The mandril is made a little smaller in diameter than the bore of the tube intended to be manufactured, while the periphery of the front

Fig. 114.

orifice *a* should be equal to the desired thickness of the tube. The mandril is made hollow, to allow a current of air to pass through,

Fig. 115.



driven by machinery applied at the end marked *b*. *d d* is a tubular mould, consisting of two pieces connected by hinges, so as to be closed or opened at pleasure. *f* is a tubular rod by means of which the pipe is drawn, which terminates at the inner end in an elongated cup *e*, and has a disc attached to it a little behind the cup. The disc is of the diameter of the intended tube of glass.

The vessel *A* is filled with fluid glass, which is preserved in this state by an air-hydrogen jet blowing upon it. The cup end *e*, of the tubular rod *f*, having been previously heated, so as to cause the glass

to adhere to it, is then introduced into the orifice *a*, Fig. 115, 2. The rod is now drawn forward with a rotatory motion, by which the glass is carried into the mould *d d*, which, when filled, is immediately closed. The workman at the same time shuts the outer and open end *h* of the tubular rod *f*, by means of a suitable valve, causing the current of air passing through the mandril *b c* suddenly to accumulate in the interior, and the glass to assume the shape of the mould. The glass tube is then detached from the rod and mandril, and annealed in the ordinary way.

Fig. 115, 4, shows the exterior of the iron tube *f*, ribbed obliquely for the purpose of forming a sort of male and female thread in the glass tube.

A full account of this application of glass, and the means of connecting different lengths of tubing, are described in the Inventor's Specification in the "Repertory of Arts." The above extract is sufficient to convey a general idea of the nature of this invention.

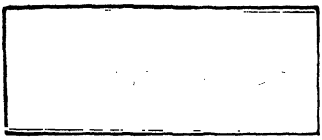
Messrs. Coathupe, of Bristol, England, are now manufacturing tubes of very large dimensions for conveying water or corrosive liquids, gas, &c., and for other ornamental purposes. These tubes are drawn in the usual manner. They may be obtained 15 feet long, and have any bore not exceding $1\frac{1}{4}$ inches, with a thickness of about $\frac{1}{4}$ inch. Tubes of about 3 inches bore are the largest that have yet been made for ordinary purposes, and these seldom exceed from 5 to 6 feet in length, weighing from 26—28 oz. per foot. When but little internal pressure is to be exerted upon a series of these tubes, they may be connected by gutta percha or vulcanized India-rubber joints. It is also proposed to join them by collars of semi-fused clay and ground glass. The ends of the tubes about to be united are overlapped with a strip of canvas, covered with adhesive cement. A clay collar is placed centrally over the junction, and the ends of the collar being luted with clay, the cement is poured in through two holes in the collar, left expressly for the purpose, until the whole cavity is filled.

OF GLASS FOR OPTICAL PURPOSES.

The application of glasses to microscopes, telescopes, cameras, &c., arises from the power which they possess of refracting light, or turning it aside from its original direction; the property of decomposing white light and giving rise to color is much opposed to this application of glass, as in the place of a single colorless image, several colored images are obtained from an ordinary glass lens. An instrument constructed with lead-glass lenses produces, therefore, an image of the heavenly bodies, or of microscopic objects with a colored margin, and thus precludes the possibility of accurate observation. It is fortunate, however, that glasses of different composition possess these two properties in a very different degree; lead-glass, for instance, decomposes light in a much more marked manner, as compared with its refracting power, than crown-glass, which contains no lead. When, therefore, a concave lens of lead-glass, and a convex lens of crown-

glass are combined in the manner represented in Fig. 116, their respective effects upon light will compensate each other in consequence of the form of the compound lens; the degree of curvature can also be easily calculated and communicated to the lens, by which the chromatic effect of the glass is completely destroyed, without impairing the refractive power to any great extent. A compound lens of this kind is consequently called *achromatic*, and produces a colorless image, which is not situated in the focus of the flint-glass lens at *p*, but is somewhat removed from it at *m*. In the construction of optical glasses, two different masses are therefore requisite, the one consisting of *flint-glass*, the other of *crown-glass*.

Fig. 116.



Difficulty attending the Production of Optical Glass.—The difficulties attending the production of flint-glass lenses are very great, as, to avoid the use of very imperfect reflectors, astronomers require them of several feet in diameter, and large masses of metal are much more subject to imperfections. Impressed with the importance of the subject, the Society of Arts of London appointed a commission in the year 1824, to investigate the cause of the difficulties, and endeavor to discover a sure method of preparing flint-glass lenses. Faraday (at the head of the commission) drew up a report, supported by a long series of experiments, in which the latter point in question was only partially answered, while the former was solved in a sound and interesting manner. According to Faraday, the ordinary defects in flint-glass, arise either from a kind of devitrification, which, however, seldom occurs, and can easily be prevented in all varieties of lead-glass; or they are produced by bubbles and striæ, which it is very difficult to avoid. The injurious effect of the bubbles is less prominent than would at first sight appear, few only are left when care is taken, and those few are of very small size. The rays of light which fall upon the glass, in passing from the denser medium (glass) into the less dense (gas in the bubbles), undergo divergence, or the contrary effect to that required in a glass lens; so that, the portion of the surface of the lens under which these bubbles are situated, may be looked upon as opaque, and without action. The striæ are of much more general occurrence, and are more difficult to avoid; they produce, by their different densities, a want of uniformity in the refractive power of the glass in different parts of the mass. This cause of variation, though not always perceptible to the eye, is present wherever a denser layer of glass comes in contact with one of less dense matter, and a streak is produced. Inasmuch as the form and curve of a lens can only accomplish the purposes for which it is intended, when the density of the vitreous mass is uniform throughout, striæ of this kind must necessarily occasion distorted images, and want of clearness. The cause of this defect is not difficult of detec-

tion. The constituents of the mixture do not melt all at one moment into a uniform mass of fluid glass, but the easily-fusible oxide of lead forms a heavy glass, containing a large quantity of lead, which sinks to the bottom, and is covered by a potash glass, with little lead in its composition; the intermixture of the two for the formation of actual flint-glass, is the more difficult, as the temperature at the bottom and sides of the pots varies often as much as 1000° C. (1832° F.) and tends to retain the two varieties of glass distinct from each other. Even stirring with iron rods—which, on account of the action of the iron upon the glass, is not desirable—does not thoroughly effect the object in view, as light aluminous glass is produced (by the action of the glass upon the material of the pots) throughout the operation, and this, notwithstanding the constant stirring, remains in the form of light streaks disseminated through the mass.

Mr. Faraday states in his paper on optical glass in the Philosophical Transactions for 1830, that he found on examining pots containing glass, not more than 6 inches in depth, made from the usual materials, and retained at a full heat for 24 hours, the following differences of specific gravity between the glass taken from the bottoms and surface of the pots:

Top	3.38	3.30	3.28	3.21	3.15	3.73	3.85
Bottom	4.04	3.77	3.85	3.52	3.80	4.63	4.74
Top	3.81	3.31	3.30.				
Bottom	4.75	3.99	3.74.				

Whence it is obvious that the lower layers in the pot, even after long-continued fusion, remain denser in the mean proportion of 4.10 : 3.43 and that great variations of density occur in the glass taken from the same horizontal layer. The same remarkable fact is observed with pieces of flint-glass broken from the cooled mass in such a manner as to contain all the layers from top to bottom; these, when acted upon by sulphuretted hydrogen, became deeply colored in the lower parts (by the production of sulphuret of lead) where the lead-glass was in excess, and not at all, or very slightly on the upper surface. Faraday proposed, as the result of his observations, the preparation of flint-glass from 1 eq. boracic acid, 1 eq. silica, and 3 eqs. oxide of lead, which should be fused together in platinum vessels; but the costliness of the utensils, and the excessive amount of oxide of lead (74 p. c.), by which, indeed, the glass acquired a specific gravity of 6.4, have rendered the plan impracticable.

Faraday obtained his heavy glass by preparing in the first instance a silicate of lead containing 1 part of protoxide of that metal to two parts of silica, by the fusion of an appropriate mixture of silica and nitrate of lead during 18 or 20 hours in a porcelain crucible. This mass was pulverized in a porcelain mortar, levigated with water and the finest powder poured off by decantation. This powder was employed in making the heavy boro-silicate of lead, which is composed as follows:

154 nitrate of lead - -	=	104 protoxide of lead.
24 of the above silicate -	=	8 protoxide of lead. 16 silica.
42 crystallized boracic acid -	=	24 dry boracic acid.
		152 boro-silicate.

The nitrate of lead, the silicate of lead, and the boracic acid, should be mixed in porcelain mortars. The mixture is then placed in porcelain crucibles heated to redness before the mixture is introduced. The boracic acid loses its water, and the nitrate of lead is decomposed, the boro-silicate is formed into a homogeneous mass by constant stirring with a platinum spatula. The *found* is then ladled out with a platinum spoon and cooled on a platinum dish.

The glass is now fined by a second fusion in a platinum tray, and spongy platinum in the porportion of 8 grains to every lb. of glass is added, which very much facilitates the evolution of the bubbles of gas which would otherwise remain in the glass. The spongy platinum easily subsides on stirring the vitreous mass, and remains slightly attached to the bottom of the tray. Great care is requisite in fusing a mass containing so large a quantity of lead, to prevent the carburetted or hydrogen vapors of the fuel from coming in contact with the glass, which would be rendered black by their agency, from the reduction of the oxide of lead. This is effected by causing a current of pure air, free from dust, &c., to play upon the fusing glass in a furnace, constructed specially for the purpose, or by placing the tray with the glass in a muffle, similar to those used in the porcelain painting works, and enclosing this muffle in another somewhat larger, allowing a current of air to pass between the two, so as to destroy any reducing vapors that might permeate the substance of the muffle, and also another current of air to pass into the inner muffle, and surround the glass with abundance of oxygen.

The spongy platinum effectually prevents any air-bubbles from remaining in the glass, but no other remedy has been found for the streaks, than a constant process of stirring and mixing during several hours, until the heat gradually being diminished, the mass becomes so thick that the platinum stirrer is moved with difficulty; the glass is then allowed to cool very slowly indeed in the furnace. Faraday's furnace was so arranged that the cooling was not fully complete till four or five days after the perfecting of the glass.

The improvements in the manufacture of flint-glass are all directed to the apparently unimportant point of avoiding bubbles and waves, and to the incorporation of as much lead with the glass as possible without imparting a yellow color to it. That the refractive power may not be too small, the specific gravity should not be less than 3.1.

At a period much prior to Faraday's experiments, Frauenhofer had succeeded, at the optical establishment of Benedictbeuren, near Munich, where the celebrated telescope of the Dorpat observatory was made, in producing large lenses, free from striæ. The secret of his

process passed, at his death, into the hands of von Utzschneider. The most important improvements were made by Frauenhofer subsequent to the year 1813, when his celebrated pupil, Guinand, senior (from Brennets, in Switzerland), had already left him, to erect the institution at Choisy-le-Roi, near Paris, where he first introduced his important improvement, consisting in the substitution of a stirrer of the same material as that composing the pots, by which the glass could be constantly stirred without having its color impaired.*

Guinand's son succeeded his father in the Institution of Choisy-le-Roi, and this has since passed by purchase into the hands of Bontemps, who appears to have solved the problem with reference to the manufacture of flint-glass. In the year 1828, lenses were made by him from 132 to 150 lines (11 to 12½ inches) in diameter, perfectly free from striæ, but like those of Guinand, containing some bubbles. Since then he has succeeded in fabricating much larger glasses, perfectly faultless, of sp. gr. = 3 5 to 3.6, and the process by which these were prepared has been published by the Academy of Paris, and is briefly described as follows:

Bontemps' Flint-Glass.—The mixture of ingredients comprises 200 lbs. of pure sand, as much pure minium, and 60 lbs. of calcined soda, which together form a single charge of 460 lbs.† Why soda is employed instead of potash, appears strange, but is not explained by the inventor of the process. The composition thus corresponds very nearly with 15 equivs. silicic acid, 6 equivs. oxide of lead, and 4 equivs. soda, so that the product is, in all probability, Guinand's flint-glass, in which the potash is replaced by soda. The melting is carried on with coal as fuel, in a furnace specially constructed for the purpose, and represented in Figs. 117 and 118. It is intended for one pot *A* only, covered with a hood *b*, the mouth of which enters the working-hole *d*, so that the glass is accessible to the workman, but not to the fire. On each side of the round siege *C*, are the bars *r r*, the teazing-holes of which at *a* and *a'* are opposite each other (shown by the dotted lines in the plan). The flame thus surrounds the pot on all sides, and that its action may be everywhere uniform, it is allowed to escape by six symmetrically placed flues $f_{\prime} f_{\prime} f_{\prime}$ which are

* The two analyses of flint-glass made by Guinand, cited at page 26, lead to the formula $2(2KO,3SiO_3)+3(2PbO,3SiO_3)$ when the adventitious quantities of alumina and lime are not taken into calculation; whence it may obviously be deduced, that flint-glass has the same constituents as crystal, but that these are not in the same state of saturation.

† The following compositions are given for optical flint-glass in the Dictionnaire des Arts et Manufactures, 1847.

	BONTEMPS.	GUINAND.
White sand - - - - - -	261	225
Minium	261	225
Potashes, 1st quality	60	52
Borax -	18	4
Nitre -	"	3
Manganese	"	1
Arsenic	"	1
Residue of previous operations	"	89

in connection with the apertures f f' f', Fig. 117. The pot can be removed and replaced through the door g (consisting of a brick made

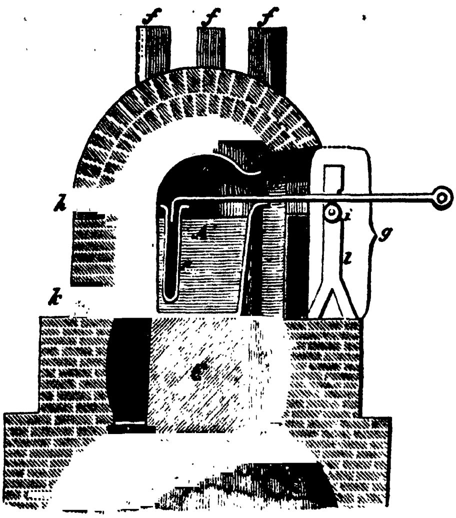


Fig. 117.

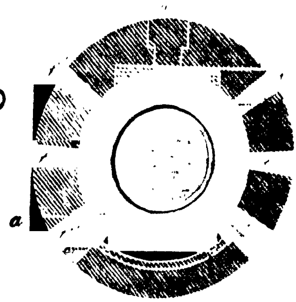


Fig. 118.

of clay), in which the working hole is situated; below the second working-hole h, is an opening k, through which instruments can be introduced for fixing the pot. The upright l, with the roller i, are for the support of the iron stirring-rod, which is inserted into the clay cylinder p.

As soon as the pot is placed upon the siege, and is sufficiently heated, the melting commences with 20 lbs.; at the expiration of an hour, 40 lbs. more are introduced; at the end of two hours, 80 lbs. in addition, and so on at four successive intervals, until, after eight or ten hours, the whole charge has been introduced. That too much time may not be lost in the introduction of each charge, the hood b is removed, but an opportunity is taken for its removal when there is no appearance of smoke in the furnace, and the coal is all in a state of coke. The constituents are then left to react upon each other for four hours; the hood is again detached, and the clay cylinder, carefully cleansed from dust or ash, is inserted, and the mass is stirred by means of the iron hook. The cylinder remains swimming in the melted glass, and can be hung by its broad rim to the edge of the pot, whilst the hood is adapted and fresh coal added to the furnace. After five hours, when the mass is tolerably cleared, the stirring, a very laborious and tedious operation, begins, and is repeated every hour, the red-hot iron stirrer being exchanged for a cold one, with only one very important interruption, the *tise-froid* (*kalt-schüren*). It is well known that flint-glass, however much it may have been fined in the greatest heat of the furnace, again evolves bubbles at a lower temperature before becoming cool. The object of the *tise-froid* is to allow this evolution of gas to proceed, and it is begun when six stir-

ring-rods have been changed, or as many hours have been employed in stirring. In two hours from this period, the bubbles have ceased to appear, and the full melting heat is continued with uninterrupted stirring for as many hours, until the mass indicates the close of the melting process by a certain degree of consistence, when the stirring must cease, and the furnace be completely closed. The process has then lasted thirty-three hours, and the furnace must now remain untouched for eight days, until the glass is completely cold.

The metal in the pot, with the exception of a few fragments, generally forms one continuous mass, the two opposite and parallel surfaces of which are ground and polished; the nature of the interior is thus rendered visible, and a knowledge of the position of the striæ obtained (these are never entirely absent, but are generally confined to one particular spot), so that pure pieces may afterwards be cut out. These are gently heated and softened in a furnace, moulded into the form of a lens in a press, cooled and polished.

Nearly in the same manner, but with greater certainty, crown-glass lenses are obtained from a mixture consisting of 120 lbs. sand, 35 lbs. purified potashes, 20 lbs. pure soda-ash, 15 lbs. chalk, and 1 lb. arsenic.

The following compositions are given in the Dictionnaire before quoted:

	BONTEMPS		GUINAND.
	1840	1846	1840
White sand	360	360	400
Carbonate of potash	105	—	160
Carbonate of soda	60	150	—
Carbonate of lime	45	84	—
Borax	—	—	20
Minium	—	—	20
Perox. of manganese	—	—	1
Arsenic	3	6	—

Bontemps has offered the French Academy, through the astronomer, Arago, to make lenses for a telescope, 22 inches in diameter, at the following rates:

	francs. £.
Flint-glass disc, 22 inches in diameter, weighing 80 lbs., at 5 frs. per lb.	400=16
Softening the mass for moulding	150= 6
	550=22
Crown-glass disc, weighing 50 lbs., at 5 frs. per lb.	250=10
Softening and moulding	200= 8
	450=18

Formerly, a flint-glass disc alone, of these dimensions, would have

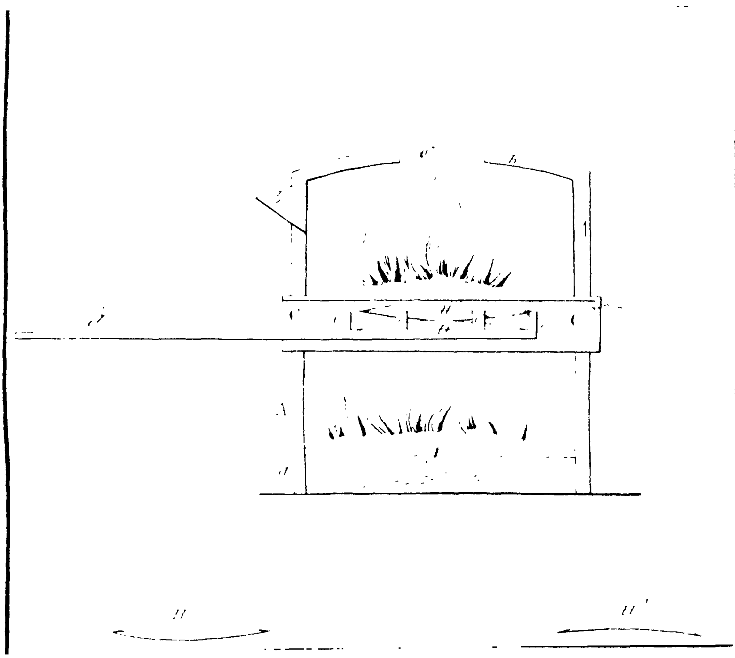
cost £1,600, *i. e.*, more than seventy-two times as much. The same optician offers to make discs of 4 feet in diameter, of flint-glass, for £100 each.

Very valuable experiments upon this subject have also been made by Körner, Steinheil, and Döbereiner.

[*Parabolic Lenses.*—Mr. Henry M. Paine, in 1846, received a patent of the United States for a mode of improving the character of optical glasses, by converting double convex lenses into concavo-convex ones, for the purpose of rendering such lenses parabolic.

The manner in which the operation of Mr. Paine is carried on will be understood from an inspection of the accompanying Fig. 119, where

Fig. 119.



A is a furnace of a square or cylindrical form having in its arch *B*, a passage or passages *a*, through which the products of combustion escape. *f* is the grate on which the combustion is carried on. *C* is an oven or muffle, into which, on the conical platina support *D*, called a curvator, and surrounded by the uprights *e*, *e*, *e*, *e*, is conveyed the lens *H*, intended to be operated on; the handle *d*, enables the operator to carry the lens to such a distance within the muffle as may be found necessary in order to give the degree of heat required.

The fuel is supplied to the furnace by the passage or hopper-way *b*. Air gains admittance to the grate by the ash-pit door *g*, which serves to regulate at pleasure the rapidity of combustion, and of course the intensity of the heat. As fire is burning both above and below the

muffle *C*, a very equable temperature may be given to all parts of it; and the softening of the lens *H*, may thus be effected on all sides at once. When the lens is sufficiently softened to bend down over the conical supporting base, or curvator *D*, it becomes changed from the form of *H* to that of *H'*.

The inventor states that as there is an optical law which governs the radius of the concave surface of parabolic or elliptic lenses, the surface of curvators is ground in conformity thereto, and as the focal lengths and diameters of lenses vary, so must the size and curvature of the curvators. The curvator may be concave, and a double concave lens may be placed on its edges, and being heated may be allowed to sink into its cavity; the convexity will then be spherical and the concavity parabolic.]

COLORED GLASS.

The property possessed by the greater number of the heavy metallic oxides of producing colored compounds with silica, which can be combined in all proportions with ordinary glass, affords full scope for applying the discoveries of science, and opens at the same time a wide field for the exercise of artistic talent, the effects of which are rendered more brilliant by the optical properties of the glass. Although glass of every variety of composition can be colored at pleasure, yet in individual cases, it depends upon the object in view, and upon the nature of the color, whether a glass void of lead, or a lead-glass with its higher refractive power, is employed as the basis for the coloring material. The object is either to adorn with color the articles of Bohemian glass or crystal, of the manufacture of which we have spoken already; *colored glass*, in a limited sense of the word, and this is effected more easily with crystal, than with glass free from lead; or to imitate precious stones, gems, and cameos, by imparting to glass their proper tints, *glass-pastes*, for which purpose lead-glass, on account of its greater brilliancy, is more appropriate; or, lastly, real *glass-painting* is the object desired, in which case colored lead-glasses are prepared as pigments, and applied with the brush to the finished objects, upon which they are subsequently fixed by fusion.

In all these cases the effect is calculated for transmitted light, or for transparent colors. The opposite effect, depending upon reflected light, as in an ordinary painting, is obtained by *enamel*, and by this we understand easily-fusible opaque lead-glass, which, like the translucent glasses, can either be used as basis or as pigment. The painted glaze upon porcelain and earthenware is an instance of the latter application.

Although it is impossible to enter into the minute details of this most extensive branch of the subject, yet it will be necessary to take a glance at the nature of the pigments, in order to understand the principles of their application to those few cases which we shall here mention.

Yellow.—Charcoal, either by direct addition, or incorporated with the glass by the charring of wood or soot, imparts a dirty *yellow* color to it, which, as the quantity increases, passes into a dark brown, without lustre, and is contained in a very fine state of division, if not dissolved in the glass.* Little use is made of this substance as a pigment at present, for a far superior yellow color is produced by *antimony* (which is the cheaper), or by *silver.*

Yellow with Antimony.—The antimony is generally added in the state of glass of antimony (*vitrum antimonii*), which is obtained by roasting sulphuret of antimony to the state of antimonious acid, and melting it with from 3 to 5 per cent. of undecomposed sulphuret of antimony. The antimonious acid is converted by fusion with sulphuret of antimony, with the evolution of sulphurous acid, into a transparent hyacinthine mixture of oxide and sulphuret of antimony, and glass of antimony. Antimonite of potash (*antimonium diaphoreticum*) answers the same purpose.

In Bohemia an *orange yellow* is prepared with glass of antimony, minium, and a little oxide of iron.

The method of treating glass with silver is very peculiar (*Lusur*). A mixture of powdered clay and chloride of silver (horn silver) is prepared, which is not mixed with the glass in the pot, but is applied to the surface of the ready-made articles. On re-heating these in a muffle, the silver penetrates to a certain depth into the glass before the latter softens, and even before the coating is firmly attached to it. It can, therefore, be scratched off when cold, and the yellow color then appears in its full purity and brilliancy. That the alumina exerts in this operation something more than a mere mechanical action, is proved by the fact, that the yellow silver color is not produced in any kind of glass, and can only be successfully brought out with glass that contains alumina.

Yellow with Uranium.—*Oxide of uranium* produces a beautifully delicate, but costly yellow; which has something of a greenish hue.

The commercial oxide of uranium, used for coloring glass, generally contains traces of iron, and to this source the greenish hue of the yellow glass is attributed.

Red, with Oxide of Iron.—A cheap and very common brownish-red color is produced by the addition of *oxide of iron* (F_2O_3) to the glass mixture, either in the state of bloodstone, ochre, or as pure oxide, prepared by heating the nitrate.

Red, with Suboxide of Copper (Cu_2O).—Glass colored red by suboxide of copper, was known at a very early period, as has been proved by the analysis of a glass paste found at the Villa of Tiberius, on the Island of Capri, which yielded 6.73 per cent. Suboxide of copper played a very important part in the mixture of colors used by artists in glass for producing the brilliant red colors of window panes, until that art sunk into oblivion, to be called to life again in our own times. For this revival of the art we have chiefly to thank Dr. Engelhardt

* The yellow color of ordinary glass bottles is due to this cause.

(1827). Suboxide of copper may be prepared by heating chippings of copper to redness, or commercial copper scale is employed, which mainly consists of copper in this state of oxidation; if, during the fusion of the glass in the pot, the suboxide finds an opportunity of uniting with more oxygen, to which it is very prone, the oxide is produced (CuO) which colors the glass green instead of red. All the recipes consequently advise the omission of oxidizing agents in the mixture, and the substitution of reducing substances, such as charcoal smithy ashes, protoxide of tin, soot, decayed wood, argol, &c. By these means the green color of the glass may be re-converted into red. Glass containing suboxide of copper does not exhibit its peculiar color immediately on leaving the crucible; it is, in the first instance, nearly colorless, with a slight tinge of green, but becomes deep red when, after having cooled, it is heated a second time at a lower temperature. With small quantities, the heat of a candle is sufficient to produce this extraordinary change, which has not yet been satisfactorily explained.

H. Rose* has lately explained this phenomenon by the assumption that a colorless neutral or acid silicate of the suboxide is formed at a high temperature, and that the subsequent softening of the colorless glass at a low temperature causes the decomposition of this compound, and the separation of a portion of the suboxide, which then colors the glass.

The coloring power of suboxide of copper is so intense, that the smallest quantity reddens the glass to such a degree, as to render it opaque, and it is, consequently, almost impossible to command any desired amount of tint in using it. A window pane of ordinary thickness, colored by this substance, is no longer permeable to light, and this is the case in a still greater degree with vessels destined for grinding. To contend with this difficulty, a colorless basis is often coated with a layer of reddened glass (or is *flashed*), which can then be reduced by grinding until the proper tint is attained. Thus, in preparing red panes for the glass painter, two pots adjoining each other in the furnace are filled, the one with colorless, the other with red glass. The workman first collects a little red glass at the end of his pipe, and then the requisite quantity of white glass to form a cylinder; this, when extended, forms a sheet of glass composed of a layer of red and white glass, the respective thicknesses of which are in proportion to the quantities taken from the pot. Other articles are first blown from white glass and then dipped into the pot containing the red glass. As the colored coating can be completely, or only partially ground away, a very ornamental appearance can thus be given to glass vessels, and the process has consequently been extended to other colors, as purple, green, violet, blue, &c., in which too great intensity of the color was by no means the cause of the adoption of the practice. The brilliant colors in the glass paintings

* Pogg. Ann. vol. 72, p. 556. Or Journal of Chem. Soc., No. 176.

of the middle ages, were erroneously attributed to the presence of gold, during the time that the art had fallen into disuse.

Bedford has invented a process for staining glass in sheets or vessels after they are cut and polished with copper. This process is said to answer best with glass containing no soda. One part sulphuret of copper, 2 parts forge scales, 3 parts anhydrous sulphate of copper, and 4 parts of calcined yellow ochre, are ground together as finely as possible with essence of turpentine, which has become rather thick by exposure to the atmosphere. This mixture, which is of the consistence of cream, is laid upon the surface of the glass with a brush, and allowed to dry. The articles covered with it are then placed in an ordinary stainer's muffle, and heated as strongly as the glass can be subjected to without melting, the fire is then drawn off and the glass is allowed to cool slowly. The pieces, which now present a greenish-yellow appearance when viewed in an oblique direction, are to be placed in a close muffle with a quantity of small coal, and exposed again to the same degree of heat, and the vapors arising from the combustion of the coal. On again cooling, the glass exhibits a brownish-red appearance, and is heated a third time, when the desired red color is obtained. A single series of operations is not always successful.

Red, with Gold.—An equally brilliant color is at present not unfrequently obtained by the use of gold, which, according to circumstances, can be made to assume a scarlet, carmine, rose, or ruby tint. This application of gold was first introduced by Kunkel, who used for the purpose the purple of Cassius (named after its discoverer); since that time it was generally supposed that gold could be used for this purpose in no other form, until Dr. Fuss established the contrary.

Purple of Cassius is the dark brownish-red precipitate produced in a solution of chloride of gold, by a salt of the sesquioxide of tin. According to Fuchs, protochloride of tin should be added to a solution of per-chloride of iron, until the yellow color is converted into green, and the sesquichloride of tin thus produced should then be used in a greatly diluted state for precipitating the chloride of gold. The presence of the salt of iron is said to exert no injurious action. According to Bolley, the combination of chloride of tin with chloride of ammonium is more appropriate, on account of its greater stability in the air, and its definite composition; it can be converted rapidly and with ease into the intermediate compound with chlorine (sesquichloride) by digestion with metallic tin ($\frac{1}{3}$ of the quantity contained in it $=10.7$ per cent.). This compound should be diluted with 18 parts of water, and the gold solution with 36 parts of water, previous to precipitation, in order to obtain a purple of the proper quality, which is then collected upon a filter, washed, and dried. The nature of purple of Cassius* is still a matter of controversy among chemists,

* Figuier has recently endeavored to show that the different precipitates bearing this name, consist of an excess of stannic acid, and a residue of constant composition $3SnO_2$,

but it is most probably, as viewed by Fuchs, the hydrate of a combination of proto-stannate of tin with a stannate of oxide of gold which is intermediate between the proto- and the peroxide, viz: $2(SnO,SnO_2) + AuO,2SnO_2 + 6Aq$, according to which it should contain 28.3 per cent. of gold. The coloring power of this substance is considerable, and the recipes recommend 1 part of the preparation of gold to 6, 9, or 12 parts of the mixture of ingredients for glass.* Fuss has proved, in a prize paper (read before the Society for the Promotion of Manufacturing Industry in Prussia), that ruby colored glass may be obtained without the use of purple of Cassius, when the powdered ingredients for the glass are mixed, previous to fusion, with oxide of tin and the solution of gold; the mixture then assumes the appearance of moist gray sand. Thus also many old statements (Neri, Libavius), and others of more recent date (Besseyre, Splittgerger), as well as the practice in the Bohemian and Silesian glass-houses, distinctly prove that the simple addition of a solution of gold to the flux, without any oxide of tin, is capable of producing rose and carmine-colored glass. The purple of Cassius itself must no doubt undergo decomposition during the fusion of glass at a temperature that exceeds the melting point of gray cast-iron. Similar and equally extraordinary changes are produced in the color of auriferous glass at different temperatures, as have already been noticed with reference to glass colored by suboxide of copper. When the fusion is completed, the glass is colorless in the pot, or is sometimes greenish or topaz-yellow in the middle, and red or brown-red at the bottom. The colorless portion remains colorless when cooled; but when re-heated during or after working, it quickly assumes a light red color, which spreads from the heated point over the whole mass, and increases in intensity until it is almost opaque and appears black by reflected light. This is the case whether the glass is heated in an oxidizing or deoxidizing atmosphere, and even when in vacuo and no other apparent change occurs, except a slight alteration in the density (from 0.005 to 0.008).

Ruby glass that has been thus colored red, can be again rendered colorless by fusion, and a slow process of cooling; its color is again produced by a repetition of the heating. If too frequently melted or exposed to an excessively high temperature, its nature is changed; it becomes light brown with a tinge of violet, and grains of gold separate. Lastly, when colorless ruby glass is suddenly cooled, it cannot be again made to assume color, but remains permanently colorless. These phenomena are the more incapable of theoretical explanation, as we are totally ignorant of the kind of combination in which the gold is contained in the colored glass. The assumption of a

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$Au_2O + 4Aq$ (proto-stannate of gold), which can be separated by potash; he has not, however, explained the incongruities between his own observations and those of his predecessors, for, according to Berzelius, the purple of Cassius is not altered by a solution of potash.

* The quantity here stated is far too much, and would render the glass excessively expensive; it is well known that 1 part of the preparation of gold, will distinctly color as much as 30,000 parts of glass.

silicate of the oxide in ruby glass, appears highly questionable from the character of the oxides of this metal, and yet the view taken by others, that the color is attributable to the metal in a high state of division, is totally devoid of direct proof, although it has acquired a certain degree of probability by the analogies lately pointed out by Schubarth. In the former case, the change of color would be accounted for by the conversion of oxide of gold into the purple-colored intermediate oxide, with the transference of oxygen to some other constituent of the glass—in the latter, the explanation is not so easy.* The brilliancy of the color diminishes in the less deep tints, and is at its highest in the saturated glass.

Colorless glass is frequently flashed or coated with ruby glass, not by immersion into a pot containing glass of that color, but by attaching a part of a cake of ruby color, ready prepared, to a globe of hot colorless glass from the pot, the prepared cake of ruby color is more fusible than the mass which is to be coated with it, and when the two are therefore warmed together, the ruby glass melts first, and by the dexterity of the workman can be disseminated pretty equally over the whole surface of the globe; on subsequently blowing the glass vessel, the thickness of the color becomes remarkably uniform over the entire surface.

These cakes or rolls of color are prepared in special manufactories for the Bohemian glass-houses, and the process of manufacture is said to be as follows:†

The glass used for preparing the cakes of ruby color (called *schmelze*), is composed of silica 500, minium 800, nitre 100, calcined potash 100. A solution of gold is then prepared by treating 10 grammes‡ of fine gold with 180 aqua regia, and the aid of heat; when all is dissolved the whole is poured into a vessel holding about a quart, which is then filled up with aqua regia. It is then poured into a second graduated vessel, and 5 times its bulk of water is added. Of this solution $\frac{1}{80}$ is then mixed intimately with:

512 of *schmelze*
48 of prismatic borax
3 of oxide of tin
3 of oxide of antimony,

all in the state of very fine power. The whole is then heated for 12 or 14 hours in an open crucible, placed in a glass-furnace, and then suffered to cool in an annealing-oven. When cool, the crucible is broken and the color extracted. It is not necessary to use closed crucibles, as some manufacturers assert. If more acid is used than is prescribed above, the crucible is attacked, but the color is more solid.

According to the director of one of the glass-works in the neighborhood of those of Bohemia, a very beautiful ruby color may be obtained in the following way: Dissolve by heat 1 grm. (15.4 grs.

* Compare p. 115. † Chem. Gaz. iii. 268. ‡ 1 gramme=15,438 grs. troy.

troy) of fine gold in an aqua regia composed as follows: 12 grms. nitric acid, 12 grms. muriatic acid, and 1 grm. sal-ammoniac. Again, dissolve by heat 1 grm. of tin in an aqua regia composed of 20 grms. nitric acid, and 6 muriatic acid; then pour the two solutions into a large vessel containing already 500 grms. of clear water, and mix them intimately by agitating the vessel after corking it. The red precipitate of purple of Cassius which forms, is washed and dried with care. A peculiar glass is then prepared by mixing together 40 parts of very pure quartz pulverized, 16 parts of nitre, 8 parts of borax, 1 part of white arsenic, 1 part of cream of tartar, finely pulverized, and sifted through silk, and a greater or lesser quantity of the purple of Cassius, according as you want a more or less deep color. This mixture is introduced into a clay crucible, made expressly for the purpose, not glazed, and of about the capacity of 5 quarts, or else in an ordinary glass-pot; it is then heated in a glass-furnace, or in a small furnace made expressly for the purpose, taking care to stir the materials continually until they have attained a dull red heat. The crucible is then covered, and the heat continued for some time.

When the mass is perfectly melted, and no more bubbles are formed, the crucible is removed, and after being suffered to cool for 4 or 5 hours in a cellar, it is broken, and the glass obtained is separated with care from the impurities which it may contain; it is then ground and sifted. If the following mixture be now melted together in a small crucible placed in the glass-furnace, viz.: 128 parts of pure quartz pulverized, 64 parts of nitre, 3 parts of borax, and 3 parts of white arsenic, and the glass thus obtained be poured into cold water, ground and passed through a sieve, then mixed with the colored glass prepared as above, and melted in a glass crucible, a glass will be obtained, which, when worked up into articles of a thickness not exceeding 0.16 to 0.2 inch, takes a beautiful ruby color when exposed to the smoke obtained from burning fir or alder wood.

Bohemian Ruby.—They prepare besides, in Bohemia, a peculiar ruby color, which is also employed in cakes, and has received the name of *Bohemian ruby*. It is prepared by melting together quartz powdered and fritted 100, minium 150, potash fritted 30, borax fritted 20, sulphuret of antimony 5, peroxide of manganese 5, fulminating gold rubbed in with oil of turpentine 5. If a little more fulminating gold is used, a magnificent ruby color is obtained.

Fulminating gold is obtained by precipitating the solution of gold in aqua regia by ammonia, and stirring the liquid for some time. The precipitate is then collected upon a filter, and washed rapidly with boiling water rendered slightly ammoniacal, then dried at a very low temperature. A powder is thus obtained of a deep brownish-yellow, the manipulation of which requires great precaution, as it is very explosive.

The following is the composition of Venetian ruby glass according to Böhme.

Gold	0.0492
Peroxide of tin	0.6900
Peroxide of iron	2.2000
Oxide of lead	22.9300
Magnesia	0.5000
Lime	3.8000
Soda	5.7960
Potash	6.7000
Silica	58 9800
Arsenic	trace
	101.6452

With Manganese.—It has already been stated above, that oxide of manganese produces an amethystine glass. This color can be obtained by the addition of pure peroxide of manganese, but care must be taken that the sesquioxide is not reduced by the carbon in the mixture of ingredients, or by the soot of the flame, into protoxide, which affords no color.

Green.—A green color can be obtained very easily, and in a variety of ways. A slight tint of little brilliancy is produced by *protoxide of iron;* the emerald-green color imparted to glass by *oxide of copper* (CuO) is much more beautiful. With this object in view, the glass is mixed with the product obtained by heating copper to redness with access of air, copper scale, or better with powdered and dried verdigris, which is then decomposed in the fire, and converted into oxide by the oxidizing agents. In both cases precautions are necessary tô prevent the protoxide of iron from being converted into peroxide, and the oxide of copper from being reduced to suboxide. The observation, that lead-glass is most appropriate for coloring with oxide of copper, is explained by the yellow color of lead-glass aiding the conversion of the bluish tinge of the copper into green. It is remarkable that glass which has been deprived of its transparency, and is dull, or only translucent, is converted into a deeper blue or turquoise color, and not into emerald-green, by oxide of copper. This property is occasionally made use of.

The purest and most brilliant grass-green color, less common on account of its high price, is produced by oxide of chromium (Cr_2O_3), which occurs as a pigment in commerce. It is prepared from the bichromate of potash by the reduction of chromic acid with the aid of sulphur, sulphuret of potassium, sal ammoniac, charcoal powder, &c., and after precipitation, is dried with the expulsion of its water of hydration, and obtained as a dark green powder.* In Bohemia two varieties of emerald-green are known; *ancient emerald-green*, prepared with oxide of copper mixed with a small quantity of finery cinders, and *modern emerald-green*, which is far more beautiful than the

* Chrome green has a yellow tint when placed by the side of copper green. A fine emerald-green is obtained from a mixture of the oxides of copper and iron; copper alone affords a cold blue color.

preceding, and is prepared from a mixture of the oxides of nickel and uranium.*

Blue.—The only true blue color is produced by oxide of cobalt (CoO), which is equally applicable to lead glass, in which case the tint is not so intense, as to glass containing no lead. For the finer articles and for glass painting, this pigment is prepared, according to the greater number of recipes, by precipitating the salts of cobalt by a carbonated alkali; similar products are found in commerce, under the names, black and red oxide of cobalt, &c. The coloring power of oxide of cobalt is so intense, that pure white glass is rendered sensibly blue by the addition of $\frac{1}{1000}$th part of the oxide;† the properties of the ores of cobalt in coloring glass, observed by Brandt long prior to the discovery of the metal cobalt, and the beauty and durability of the blue cobalt glass gave rise to the establishment of the *manufactories of blue color*, in which blue cobalt glass (ground) was produced as a pigment under the name of *smalt* or *zaffre*.

Smalt, Zaffre.—The preparation of smalt was invented in the first half of the 16th century (1540–60) in Saxony, and has since been extensively carried on as the only metallurgic process connected with the cobalt ores. The ores, with the exception of a few rare minerals, as earthy-cobalt, cobalt-vitriol, cobalt-bloom, &c., are chiefly of two kinds, viz., *speiss-cobalt*, or bin-arseniuret of cobalt ($CoAs_2$), and *glance-cobalt*, or bin-arseniuret of cobalt and bisulphuret of cobalt ($CoAs_2,CoS_2$).

The analysis of these minerals yielded:

	SPEISS-COBALT.		GLANCE-COBALT.	
	Crystalized from Reichelsdorf.	Massive from Schneeberg.	Massive from Tunaberg.	from Skutterud.
	STROMEYER.	HOFMANN.	VARRENTRAPP.	STROMEYER.
Cobalt - -	20.31	13.95	23.44	33.10
Arsenic - -	74.21	70.37	69.46	43.47
Nickel - -	—	1.79	—	—
Iron - -	3.42	11.71	4.95	3.23
Copper - -	0.16	1.39	—	—
Bismuth - -	—	0.01	—	—
Sulphur - -	0.88	0.66	0.90	20.08
	98.98	98.88	98.75	99.88

It is evident from these results, that the cobalt in these minerals (which are rather arsenic than cobalt ores), is partly replaced by other metals: copper, nickel, iron, &c. The purest ore, containing the smallest quantity of the other metals, is glance-cobalt. Arsenical cobalt is of much more common occurrence, but is always associated with a much larger proportion of the other metals, which are not only

* Chem. Gaz., vol. iii. p. 271.

† $\frac{1}{1000}$th part of cobalt must afford a very deep blue color, as $\frac{1}{25000}$th of oxide of cobalt communicates a perceptible blue tint to the glass.

components of its chemical constitution, but accompany it as distinct minerals in the vein; these are mispickel, leucopyrite, copper nickel, iron pyrites, magnetic pyrites, copper pyrites, blende, gray antimony, galena, gray copper ore, tin pyrites, and bismuth ore. The mechanical purification, which is a process of levigation and precedes the working of the ore, does not separate these ores, which have about the same specific gravity as the cobalt ores themselves, but only the gangue, which, being lighter, is suspended in the water, and poured off while the ores subside. The purer pieces, however, are selected, and freed by the hammer from a considerable portion of the foreign minerals; the remainder is submitted to pulverization and partially purified by levigation. An admixture of tin, antimony, or bismuth, communicates a yellow tinge to cobalt-glass, as does also oxide of zinc when present in considerable quantity. The color verges into violet when small quantities of copper and nickel are present, and becomes brown with a larger addition. The same effect is produced by protoxide of iron, which, however, when not in too great excess, is rendered harmless by the presence of arsenic (as a discolorizing material).

The next object in the manufacture of blue-color is to convert the cobalt of the levigated ores into the state of oxide, in such a manner that the foreign metals shall be separated or rendered innoxious; this is done by roasting, and the oxide thus produced is then vitrified, with the addition of the purest potashes and silica.

The Roasting.—During the process of roasting (by which is always meant the exposure of the substances to a red-heat with the constant access of air), the sulphurets contained in the ores absorb oxygen, sulphurous acid is formed, and at the same time oxides and sulphates of the metals, whilst the volatile arsenic is consumed and carried away by the draught, in the form of arsenious acid. The construction of the reverberatory furnace, Figs. 120 and 121, in which this

Fig. 120.

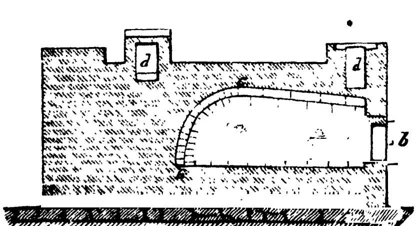
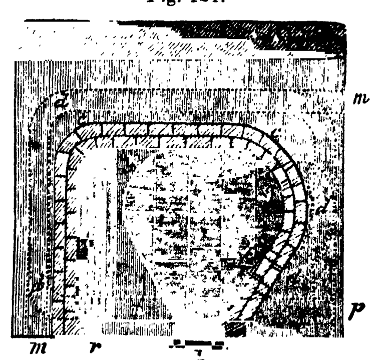


Fig. 121.



operation is conducted, is adapted to collect these volatile and very poisonous products. The arch *c c*, and the sole *a a*, of the roasting-hearth are formed of fire-stone. The powdered ore is introduced by

the working door *b b*, in quantities of 3 to 4 cwts. at a time, spread out in a uniform layer 6 inches in thickness, and this is then exposed to the flame of a wood fire on the grate *r*. The flame passes over the fire-bridge *n n*, and is carried with the volatile products through the flues *o o*, into the common flues *d d*, which are carried round the fire-place. The apertures *m m* of these flues are only intended for the purpose of cleaning, and are generally closed; through the aperture *p*, on the contrary, the smoke enters a long smooth gallery (*poison-gallery*) or a wide chamber (*poison-chamber*) which is wide enough to impede the velocity of the draught, and allow the arsenious acid time to collect and deposit.

If the ores are pure, there is no reason why the roasting should not be continued until the oxidation of the metal is complete; and, indeed, it would be disadvantageous not to do so, as the unchanged sulphuret and arseniuret of the metal would be decomposed in the subsequent fusion, at the expense of a portion of the potash, into sulphuret and arseniuret of potassium and oxide of cobalt. It is very different, however, with the impure ores as they are usually worked; nickel and copper would also be oxidized in this case by a complete process of roasting, and the oxides of these metals, which cannot be rendered innoxious by discolorizing matters, would be associated with the color and spoil it, the nickel communicating a hyacinthine, the copper a florid red or green tint to the smalt. It is therefore an obvious error to roast fully or to dead-roast ores of such a character, and it is carefully avoided in the smalt works. When the roasting is not carried beyond a certain point, arsenic remains behind on the one hand, and the oxygen absorbed is insufficient on the other to combine with all the metals which are competing for it. In the subsequent fusion, therefore, those metals (cobalt, iron, &c.) which possess the most powerful affinity for oxygen will prevail and hold back the oxygen, whilst the others (nickel, copper, silver, bismuth, arsenic, &c.) with a lesser affinity for oxygen, will separate in the metallic state (as regulus), or combined with arsenic, as speiss, and collect below the layer of blue glass. If the roasting is continued for too short a space of time, a portion of the cobalt will remain in an unoxidized state, and pass with the other metals into the speiss, when a loss of coloring-matter will be the consequence; a small amount of cobalt in the speiss is, on the other hand, a good sign, indicating that the roasting had been sufficiently advanced, and yet that enough arsenic has been left to combine with the nickel, for which it has a stronger affinity than for cobalt. Arseniuret of cobalt and oxide of nickel are mutually decomposed by fusion into oxide of cobalt and arseniuret of nickel. The following constituents have been found in speiss:

	Nickel.	Arsenic.	Manganese.	Iron.	Copper.	Cobalt.	Antimony.	Sulphur.
Berthier	49.0	37.8	—	—	1.6	3.2	trace	7.8
Wille	52.6	40.5	—	2.7	1.6	trace	—	2.5
Wöhler	52.7	44.0		1.60		—	—	1.65

It is consequently a kind of artificial ore, composed of arsenic, nickel and sulphur.

The product examined by Wöhler, consisted of the crystals which are occasionally met with in speiss, and are obviously composed of Ni_3As, with an admixture of metallic sulphurets.

When the ores contain bismuth, as is the case with those of the Erzgebirge, the greater part of this metal is extracted before they are employed in the smalt works, and the remainder is subsequently found below the layer of speiss.

A small quantity of zinc adheres pertinaciously to the cobalt, and can seldom be totally removed; the oxide imparts a greenish tint to the glass.

The Composition.—Experience has shown, with reference to the fluxes that are mixed with the roasted ore, that the earths impair the color by diminishing its purity and lustre; and the purity of the color is still more damaged by soda. Lime and soda are, consequently, omitted in the mixture, and purified potashes only are employed; this is the more essential, as the matrix or gangue which still remains attached to the ore, frequently contains lime and magnesia.

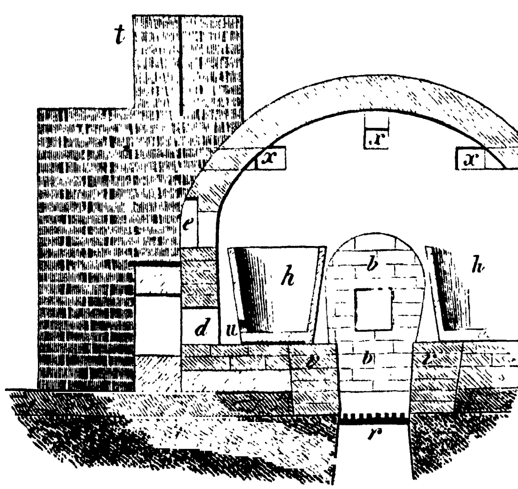
Silica is always used in the form of quartz, but is submitted to previous mechanical purification. With this object in view, the quartz is heated to redness, and thus disintegrated, it is then pulverized in a stamping mill and the meal washed, suspended in water, and the fine powder allowed to subside. The lighter earthy and ferruginous particles remain longer in suspension, and can be poured off, and by repeating the process, pure quartz-meal is at length obtained, which, when dried and heated to redness is technically called *sand.*

The mixture of the roasted ore with quartz and potashes, is carefully conducted in wooden tanks, with the addition of white arsenic, which is essential on account of the iron in the ingredients; the arsenic is used in the form of powder as it collects in the poison-galleries, and with it a small portion of oxide of cobalt is recovered, which is mechanically carried into the poison-galleries by the draught. The depth of color in the product, the proportions of sand and potashes remaining the same, naturally depends upon the amount of oxide of cobalt in the roasted ore, or upon the quantity and quality of the *schliech* employed in the mixture. If the roasted ore contains much lime and alumina, these will enter into the composition of the glass, and dilute its pure blue color. The coloring powers of the ore will therefore depend, not only upon the amount of oxide of cobalt which it contains, but also upon the nature of the substances mixed with it. In the arts, however, a great variety of tints are in constant demand. The difficulty of attaining a uniform and constant tint of blue, will be evident from these facts, as it must entirely depend upon the nature of the ingredients, and these are constantly subject to change in every consecutive roasting. As a constant quantity of potash is always employed in the smalt-works proportionate to the sum of the other constituents of the mixture (*i. e.* $\frac{1}{3}$ of the ore and sand together), the

only question that remains to be settled, is the relative proportion of ore and quartz. Two processes of testing are resorted to for establishing this point. The one test informs the workman how long the roasting must be continued in order to produce the deepest blue with the smallest quantity of ore, *i. e.* until the ore has acquired the most intense coloring power. The other instructs him as to the quantity of sand that must be mixed with the ore in order to produce a certain tint. Both tests are mere repetitions of the manufacturing process on a small scale. A series of definite tints, generally three, can thus be kept constantly on hand, and from these any required modifications can be produced, by altering the relative quantities of the ingredients. A complete set of all the gradations of color producible by the ingredients is requisite for this purpose, and also a series of specimens of all the tints of color required in commerce. As the desired intensity of color can only be produced by the most accurate attention to the relative weights of the ingredients, the latter are never mixed by measure, but always by weight in the dry state. The same degree of accuracy is not necessary in adding the arsenic, as an excess is in this case easily volatilized; it is therefore added in variable quantities up to the same amount as the ore.

Fusion.—The operations connected with the fusion of the mixture are the same as those already described under glass, and the separation of the speiss is the only essential difference, and gives rise to certain modifications in the construction of the furnaces, which are either round or square, and adapted for coal or wood; these will be more easily explained by a reference to the sketch, Fig. 122. The pots *h h* are inserted at the walled openings *b*, they are pierced at the side with an aperture for the removal of the speiss (speiss-hole), which is directly opposite the *knee-hole d.* Through this latter aperture the speiss and waste-glass are removed from the furnace, and the hole is

Fig. 122.



closed during the fusion. The working-hole *e* is situated directly above, and is used for introducing and removing the ingredients and the glass. The flame is kindled on the grate *r*, enters the furnace at *v*, and passes out through the holes *x x x* which are in connection with the short chimney *t*. The easy fusibility of the ingredients demands only an eight hours' melting, and during this time the mass is often stirred, until the glass appears homogeneous and the speiss has settled down; the stirring must then cease and the heat be kept up in order to aid the separation. The fused glass is then ladled out and poured into cold water, that it may be disintegrated and easily pulverized.

Grinding and washing.—The reduction of the glass into the state of powder is effected by two granite stones, working under water in a wooden trough, which receives the glass previously finely stamped or broken into fragments between rollers; the water, rendered muddy by the colored glass, flows constantly into a depositing vessel, and the trough is replenished as fast as the water flows away; on leaving the depositing-vat it flows into the washing-vats, where it deposits the coarser particles (called *sanding* or *strewing-blue* as it is used for the floors, and is not otherwise known in commerce). The water with suspended matter then passes consecutively through two other washing-vats, in the first of which the real pigment is deposited, whilst a still finer powder (*Eschel*) subsides to the bottom of the second. The action of water upon the finely ground powder is not merely mechanical, but a decomposing chemical effect is also produced by it. Cobalt glass, like all the varieties of glass which are prepared by fusion without the addition of lime, is not entirely insoluble in water, or rather, is separated by water into the pigment, and a partially soluble glass of a dirty grayish color, which is attacked by the water.

Other portions of the powder, as glass-gall or salts, which do not enter into the composition of the glass, are also dissolved and separated by the water. The pigment and the eschel, when the suspended matter is all deposited, are consequently again treated and stirred up with water. The water which has served for washing is collected in large tanks, and yields an impure product which is returned to the pots and re-melted.

The well-washed color is drawn off from the washing-vats, dried in the drying-house, and sifted. Intermediate tints are sometimes prepared by mixing the color with eschel. This is carried out in separate factories, as in Holland, the crude substances being imported from Saxony, and most beautiful combinations are thus obtained.

During melting, the speiss-hole is closed with a plug of clay. When the glass has been withdrawn, this plug is forced in, and the speiss allowed to flow out into iron moulds, through the knee-hole. Pure ore, consisting only of glance-cobalt, yields of course no speiss. The glass-waste that falls upon the hearth is re-melted with color of the same tint.

Smalt is applicable to all purposes in which a cheap durable blue is required as superficial color, *i. e.*, as a paint, for rendering paper

blue, for linen, &c. A pigment of this kind is only attacked by agents which destroy glass, and these are so few in number, that smalt exceeds most pigments in chemical indestructibility. Its good quality is dependent upon the purity and uniformity of its tint; the former can only be secured in the smalt works, when the ore is sufficiently pure, and it is frequently impossible to produce the highest depth of color in consequence of the poverty of the ore.

Pure smalt may be used for painting and coloring glass, but is not so appropriate for fine work as fluxes prepared with pure oxide of cobalt; whilst for less delicate purposes, for the paintings on earthenware, &c., the simple mixture of ingredients will obviously produce the same effect as the prepared pigment, as both must subsequently be burnt or fused. Indeed, large quantities of roasted ore mixed with the necessary addition of flint powder, are sent into the market under the name of zaffre or saflor.* The proportion of the ingredients in the mixture must be so arranged, that they shall yield by fusion with the proper quantity of purified potashes, the exact tint which is ascribed to them by the manufacturer. This is ascertained by the same process of comparative testing as has been described in the case of smalt.

Mixed Colors.—The colors which have been mentioned, are the simple or fundamental colors, by the intermixture of which—inasmuch as their chemical properties will admit of it—innumerable derivative colors can be produced. Thus peroxide of manganese with 6 times its weight of zaffre yields a *brown* garnet color; oxide of iron with alumina, obtained by heating a mixture of alum and green vitriol, affords a *flesh color*, as is also the result of a mixture of the oxides of gold and silver; the preparations of antimony with oxide of copper, yield a beautiful *green;* red, produced by peroxide of iron (ochre) with the yellow from silver, affords *orange*, &c. *Black*, which is nothing more than the absence of light and no real color, cannot be combined with transparency. In the absence of a substance that will yield black at once, powerful coloring materials are applied in such large quantities, that no light can pass through the glass. Amongst these are peroxide of manganese, protoxide of iron, oxide of cobalt, and suboxide of copper, mixed two or three together, according as a brown, blue, or green-black tint is required.

Hyalith or *Jasper.*—This name has been given in Bohemia to a species of glass, perfectly opaque, generally black, remarkably hard, and possessing a most beautiful lustre. It is reported to be made by fluxing slag with basalt. Its properties are such that it may be employed for boiling liquids, without any risk of breakage. The black jasper is prepared by adding:

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* The names *smalt* (*smaltam*, corrupted from *Schmeltz*), *Eschel* (from *Ashe*, ash, on account of the addition of potashes), and *zaffre* or *safflor* (corruption from σαφειρος, sapphire, on account of the blue color), were no doubt originally synonymous, until they were used at a later period to distinguish different products of the same process of manufacture. Kunkel used the word smalt as a general term for any kind of glass flux, *i. e.* white glass intended for coloring, for example, strass.

Forge scales, partially ground,
Charcoal powder in excess, and
Bone ashes in powder,

to the ordinary materials for making glass. The forge scales may be replaced by basalt or lava. A yellowish bronze-colored jasper is produced by substituting lead-slags for the forge scales, and a red by oxide of copper, &c. &c.

A deficiency of carbon causes the fracture of the jasper to present a marbled appearance, of which advantage is taken in preparing articles for sale.

It is difficult to explain the action of the carbon, which may act by reducing the higher oxides, or by a species of devitrification similar to what is noticed in the slags from blast-furnaces.

Strass.—For preparing imitations of natural gems, glass possessing the highest degree of purity and transparency, combined with the greatest possible lustre, is required; a glass, indeed, which without its hardness, approaches as nearly as possible to the diamond in other properties. This glass, which is prepared from a mixture of quartz and boracic acid, with perfectly pure potash (it is best to use caustic potash, purified by alcohol), is called strass, after its original inventor. Donault-Wieland, who has given much attention to this subject, recommends as examples, the following mixtures of ingredients:

	No. 1.	No. 2.	No. 3.
Ground rock crystal -	100	—	100
Sand - - -	—	100	—
Pure minium - - .	156	—	154
White lead - - -	—	171	—
Purified caustic potash* -	54	32	56
Boracic acid† - -	7	9	6
Arsenious acid - -	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{6}$

Whence it will be seen that strass very much resembles flint-glass, and only differs from it in containing a larger amount of lead.

The choice of crucibles is very important in preparing strass; Dumas recommends the use of Hessian crucibles, as less permeable than those made of porcelain. A porcelain or potter's furnace is employed for fusing the mixture, and the crucibles remain in the fire about 24 hours, the product being cooled as slowly as possible. The same general precautions with regard to the purity and state of division of the ingredients are necessary in preparing good imitations of precious stones, as in the manufacture of optical glass.

The analyses of Wieland's strass (p. 26) correspond with the simple formula $KO,SiO_3+3PbO,4SiO_3$, or more accurately, $3KO,4SiO_3+3(3PbO,4SiO_3)$. By fusing the colorless strass with the prepared metallic oxides, the imitations of various natural gems are obtained;

* Dumas recommends that nitrate of potash should be substituted for the potash, as being very much more uniformly pure.

† Borax was the substance originally used by Donault.

topaz is imitated with glass of antimony and purple of Cassius, or with oxide of iron; *ruby* with purple of Cassius; *emerald* with oxide of copper or chromium; *sapphire* with oxide of cobalt; *amethyst* with oxide of cobalt and purple of Cassius; *beryl* with glass of antimony and oxide of cobalt; *garnet* with purple of Cassius, glass of antimony, and peroxide of manganese, &c.

Topaz is very subject to vary in tint during fusion, according to the temperature and the time it is exposed to the fire. It passes from the white color of colorless strass to a sulphur yellow, violet and reddish-purple, according to circumstances which are not well understood. Donault's recipe is:

Very white strass - - - -	1000
Clear yellowish orange-red glass of antimony	40
Purple of Cassius - - - -	1

A very good imitation of topaz is obtained from:

Strass - - -	1000
Oxide of iron - -	10

Ruby is the most highly prized of all artificial gems, and a substance peculiarly adapted to its production, is often obtained in preparing topaz. The mixture for topaz often yields an opaque mass, translucent on the edges, and of a transparent red color, in thin laminæ. One part of this mass with 8 parts of strass fused for 30 hours in a Hessian crucible in a potter's furnace, affords a beautiful yellowish crystal, resembling strass, which, re-melted before the blowpipe, produces the most beautiful oriental ruby.

A less beautiful ruby of a different tint is obtained from:

Colorless strass - -	1000
Oxide of manganese - -	25

Emerald.—The most perfect imitation of the native emerald is produced from:

Colorless strass - -	1000
Pure oxide of copper -	8
Oxide of chromium - -	0.2

Sapphire.—A beautiful oriental blue is obtained by the use of very white strass and pure oxide of cobalt, the composition is placed in a luted Hessian crucible, and left for 30 hours in the fire. The proportions to be used are:

Colorless strass - - -	1000
Oxide of cobalt - - -	15

Amethyst.—The best composition for amethyst is:

Colorless strass - - -	1000
Oxide of manganese - -	8
Oxide of cobalt - - -	5
Purple of Cassius - - -	0.2

Syrian garnet is obtained from:

Colorless strass - - -	1000
Glass of antimony - - -	500
Purple of Cassius - - -	4
Oxide of manganese - -	4

Connected with the production of artificial gems, although the processes are of a totally different character, the following may be worthy the attention of glass-manufacturers. M. Ebelmen has succeeded in crystallizing several artificial minerals by employing the solvent power of boracic acid at a high temperature for the metallic oxides of which they are composed. The following is the plan pursued. Having weighed separately the substances that are to enter into the compound, and the fused boracic acid reduced to the state of powder, these are mixed with great care, and the powder is placed upon a leaf of platinum in a shallow cup of biscuit porcelain with a flat bottom. This cup is placed in a vessel composed of refractory clay, such as is used in baking porcelain. These vessels are cut slanting on one side, so as to establish an easy communication between the atmosphere of the furnace and the interior of the case, the volatilization of the boracid acid being thus facilitated by a constant current of air. They are then exposed to the heat of the porcelain-furnace, during the entire period of firing.

As an example, the proportions used for preparing the rose-tinted spinelle (MgO,Al_2O_3) may be given; these were:

Alumina - -	6·00 grms.
Magnesia - -	3·00 "
Fused boracic acid -	6·30 "
Green oxide of chromium	0·10 to 0·15 grms.

The mass, after being fired, is generally in the form of a rose-colored cake, on the surface of which it is easy to distinguish the facets of equilateral triangles, but on detaching the product from the platinum, the interior is generally found to contain nests of rose-colored crystals, which are very brilliant, and the form of which can easily be distinguished with a magnifier. The crystals are regular octahedrons, truncated on the twelve edges, which scratch quartz with ease.

By using borax, which is less volatile, instead of boracic acid, alumina itself has also been crystalized; the proportions employed for this purpose were four parts of borax and one part of alumina, with $\frac{1}{100}$ of oxide of chromium; after firing the mixture, a mass was obtained containing small ruby crystals, visible with the magnifier, which scratched the topaz, and exhibited a crystalline form, that left no doubt as to the identity of the substance with corundum, the mineral next in hardness to the diamond.

Glass-painting.—The earliest productions of this branch of art, stand in the same relation to those of a later date, as a copper-plate to an oil-painting, and consist of black outlines upon a ground

of white glass. These, however, were soon succeeded by glass mosaics, which were brought at an early period to the same state of perfection as by artists of the present day. Glass mosaic is that branch of the painter's art exhibted in the oldest churches and monuments of the middle ages; the paintings were made up of portions of glass cut from colored plates, and the shading was produced by fusible pigments, the pieces being connected together by sheet lead, in such a manner, that the lead coincided as nearly as possible with the outlines of the figures. At a later period, the plan of substituting transparent colors for the black was discovered, and glass-painting, in a limited sense of the word, sprung up, and was materially aided by many results of the alchemistic labors of that age, and brought to perfection by the genius of A. Dürer, Van Dyk, L. v. Leyden, and others, whose productions will ever be objects of wonder and admiration. In the 15th and 16th centuries the art rose to the highest pitch of excellence, but soon declined with the altered taste of the age, and sunk into oblivion, until again called to life in the 19th century. Since then, the art has found in chemistry, a science upon which it must always be dependent in a technical point of view, the most powerful ally, and to its aid must be attributed the rapid progress that it has made. It cannot, however, be said that the revival of glass-painting is entirely due to the progress of modern chemistry, although the preparation of the red ground (*Ueber-fanglase*) as a material for deadening the light, is of the greatest importance for producing effect; the talent of the artist has been of still more essential service, and indeed the art was never entirely lost, but only neglected, the fundamental principles of technical detail having been preserved in the works of Neri, Kunkel, Le Vieil, and others. Nobody, on the other hand, can doubt the superiority of modern productions in a technical point of view, although, considered artistically, and applied to the highest objects in church-painting, for instance, they do not present that harmony with an exalted style of architecture which is witnessed in those of the middle ages, and appear rather, by the almost painful attention to minutiæ, and littleness of conception, in contrast with the spirit of the whole.

Three essential points require attention with reference to glass-painting. The *glass to be painted*, the *color*, and the *flux*. The flux is the combination of ingredients required to produce the colored glass with the pigment prepared from some metallic oxide. Both color and flux are intimately mixed in the state of fine powder, and laid upon the glass with a brush; they are then fused, by which means they become attached to the plate of glass, and, being transparent, produce the colored effect. It will easily be conceived that success in operations of this kind, demands on the one hand, a complete vitrification of the pigment, whilst on the other, there must be no irregular extension or absorption of the color by the matrix, as this would entirely destroy the sharpness of the design, and give it the appearance of a faulty outline. In addition to this, the pieces are generally placed in the hands of the painter in a perfectly finished state as regards

form, and consequently any change of form occasioned by softening in the heat of the enamelling-furnace, must be most carefully avoided. The fusing points of the glass to be painted, and of the pigment, must therefore be as distant from each other as possible, *i. e.*, the pigment must become fluid at a temperature at which the glass to be painted does not soften, and the heat employed in burning the color must not be higher than is absolutely necessary. It will now be understood why painted articles should not be prepared from lead-glass, and why the hard Bohemian glass, which contains no lead, is peculiarly adapted for these purposes; for the same reason, the flux is rendered easily fusible by the addition of borax, minium, or oxide of bismuth.

In glass-painting, a drawing upon paper (cartoon) is placed below the glass, and the colors are applied, with this as a guide, rubbed up in oil of turpentine (or simply with water), and when dry, are burnt in. Upon the old plan, the painted sheets were placed in an iron pan, alternating with layers of dry lime, which had fallen by exposure to the air; the pan was then brought to a red heat in a furnace constructed for the purpose; the color of the glowing pan and the flexibility of some small test-pieces, or *watchmen*, were the painter's guides in regulating the heat. Muffle furnaces, constructed of clay, are now generally used, in which the muffle (a quadrangular or arched box, similar to that in Fig. 125), placed a little above the grate bars, is intended for the reception of the pieces to be burned. It is to be observed, that in preparing painted sheets, the brown or black outlines are traced on the one side of the sheet, whilst the colors are laid upon the other side; with other pieces this is not the practice.

Fig. 123 represents a section and elevation of the furnace and muffle used in France for burning painted glass vessels, &c.; Fig.

Fig. 123.

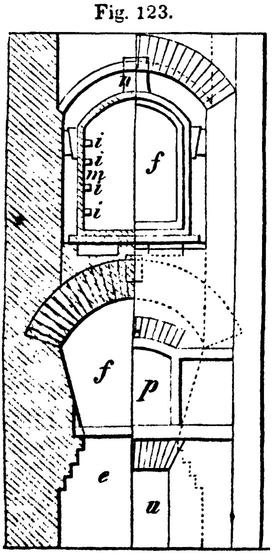
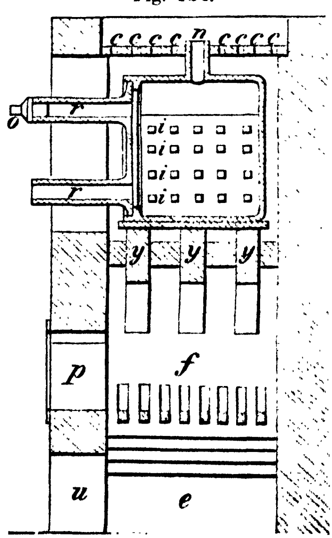


Fig. 124.



124 is a longitudinal section of the same; *e* is the ash-pit, and *u* its door, *f* the grate, and *p* the fire-door; *y y y* are the supports for the muffle *f*, *c c c* the apertures for the escape of the flame, *n* the chimney of the muffle, *i i i* are ledges on the inside of the muffle, across which bars of porcelain are laid, and upon these, plates of porcelain are placed, for supporting the pieces of glass to be burnt.

Enamel Glasses.—Easily fusible glasses, which are employed for coating metal and other vessels intended to resist the action of the fire, sometimes as a protection to the surface against chemical agencies, at others, simply as the medium for communicating ornamental colors, are called enamel. Sometimes they are simply composed of transparent, easily fusible, lead-glass, for instance, in jewelry and order-decorations. At other times, however, they are opaque, and intended to mask the natural surface of vessels composed of cast-iron, clay, or brass, and to give them the appearance of porcelain. In the latter case their composition is different. When any ingredient of the composition, which is incapable of fusion, is disseminated through the mass in a state of minute division, or separates in this state during fusion, it will remain suspended as a fine opaque precipitate in the transparent body of the glass, just as a precipitate may be suspended in an aqueous solution. When glass of this kind solidifies, the particles held in suspension will be entirely surrounded by particles of glass, and being incapable of altering their position, will render the mass opaque or milky, inasmuch as the infusible substance is white or colorless. This can be produced at any time with similar effect by peroxide of tin (SnO_2), antimonious acid (Sb_2O_3), chloride of silver* ($AgCl$), and phosphate of lime (bone-ashes). All these produce a white precipitate, and consequently, a milk-white glass, but oxide of tin and bone-ashes are to be preferred. It is obviously very easy to regulate the quantity of these substances, so as to produce a translucent glass only, or by increasing the quantity, a perfectly opaque mass. To the former class belongs the so called *bone-glass;* to the latter enamel, in a limited sense of the word, for instance, that which is used for coating cast-iron, for letters, stone-ware, &c.

Bone-Glass.—Bone-glass is prepared in considerable quantities in the glass-houses, the more common varieties for the shades of lamps, &c., from ordinary white hohl-glass, the finer sorts for grinding, from crystal, with the addition of 8 to 10, and 20 per cent. of white bone-earth, according to the degree of translucency required. At the end of the melting, the glass is found perfectly clear and transparent in the pots, and the milky color is only brought out by working, or rather by re-heating, and the oftener this is repeated, the more decided the opacity becomes. Light in passing through a troubled or turbid glass of this kind, as may be best witnessed with a lamp-shade, experiences an alteration (by absorption), and a kind of play of color is produced (as is the case with milky fluids) which is called opalescence.

* It is stated by practical men, that glass colored by means of silver, which is ordinarily yellowish and clear, becomes yellowish and opalescent in an oxidizing flame.

Opaline or *Opalescent.*—A milky-white glass, resembling alabaster or the opal, is prepared in the ordinary manner, with the addition of *more or less bone-ashes in powder. Such glass, with a green tint of a superior variety, may be manufactured from a mixture of:*

Bone-ashes,
Yellow oxide of uranium, and
Forge-scales.

It is said that the glass colored with the above mixture is likely to change color by the action of the sun's rays, and that a finer color, not liable to the above objection, may be made by substituting oxide of nickel for the forge-scales.

Oxide of tin is also employed instead of bone-ashes, but only in the enamels, as it is much dearer, and much more is required to produce the same effect.

Enamel.—Opaque enamel is composed of lead-glass containing oxide of tin. In the manufacture of this substance, application is made of the well-known fact, that a mixture of tin and lead is very much more easily oxidized at a red heat with free access of air, than either of the metals separately, in consequence of the affinity of the stannic acid produced, for the oxide of lead. A tin-ash containing lead, or a lead-ash containing tin, is therefore produced, which yields at one and the same time, lead to the flux, and the opaque body, or oxide of tin, which, with the alkali and silica, produces at once the enamel.

Rules can scarcely be laid down for the production of this substance, which must vary with the degree of fusibility, and with the degree of hardness that is required. In all cases, however, the metallic ash is first obtained by calcining 1 part of tin, with from 1 to 6 parts of lead, in a flat cast-iron vessel, at a dark-red heat, and exposed to a current of air. The more diligently the coating of oxide is removed by a rake, the quicker is the process finished; notwithstanding the minute state of division in which the yellow ash is thus obtained, it is nevertheless essential that it should be ground and poured off from suspension in water previous to use, in order that all metallic granules may be removed. The following examples show in what proportions the ash is mixed with the other ingredients:

Four parts metallic ashes (consisting of 4 parts lead with tin), 4 parts pure sand, 1 part common salt, or:

One part ash (composed of equal parts lead and tin), 1 part of quartz-powder, 2 parts of purified potashes, or:

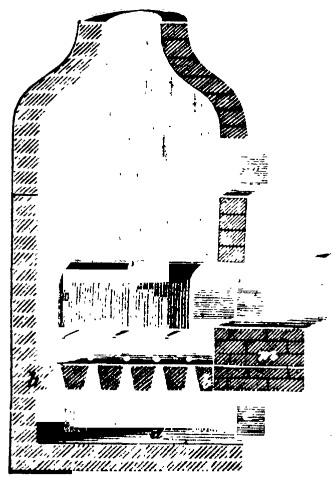
The ash of 3 parts tin and 10 parts lead with 10 parts of quartz powder, and 2 parts of purified potashes, or:

The ashes of 4 parts tin and 10 parts lead, with 10 parts of quartz-powder, and 2 parts of the purest soda.

In case the ingredients are not perfectly pure, manganese may also be used as a discolorizing material. To ensure more perfect uniformity and complete combination, the mass is customarily fritted in a crucible, and the pulverized frit is then submitted to fusion.

Enamel can only be applied after the fashion of glass pigments, that is, with a brush, and must consequently be reduced to the finest state of division. The burning is effected in a muffle *v*, a thin clay vessel, heated from without, the interior of which is nowhere in connection with the fire-space *A* of the furnace, Fig. 125, the mouth of the muffle fitting exactly the aperture *e* of the furnace. The pierced plate of clay *b b* answers the purpose of a grate, and is supplied with air by the three apertures *c c* of the ash-pit *d*. A ledge *m* is erected for convenience before the working-hole *e* of the furnace, and is supported by the cheeks *n n*. The aperture *f* is for the purpose of stirring the fire, and can be closed like any one of the others by a clay door.

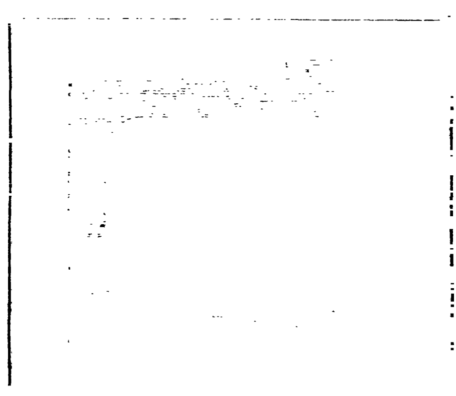
Fig. 125.



Before the work is begun, the furnace must be made red hot, the pieces are then inserted, and the aperture *e* is closed in such a manner as to leave a small crack, through which the fusion can be watched. The success of the enameling process depends upon a proper mean being maintained between that temperature which would cause the enamel to flow, and that at which it only imperfectly softens and its surface remains rough. The most common defect in the appearance of enameled articles, is caused, however, by air-bubbles, which have not found an opportunity of fully effecting their escape. These either occasion a protuberance, or when they have burst, a concavity, which frequently renders it necessary subsequently to give a finish to the piece.

In the ordinary muffle furnaces, there is considerable risk of bending or cockling the plates of glass; while in an open annealing-kiln, the direct action of the fire upon the glass is injurious.

Fig. 126.



Messrs. Chance and Badger have patented an improvement upon both the methods. Fig. 126 is a plan in section of their proposed arrangement. Fig. 127, a longitudinal section, and

Fig. 128, a transverse section; *a a* are fire-places, *b b* carriages with stone beds on which to lay the plate of glass, and *c c* sheet-iron

Fig. 127.

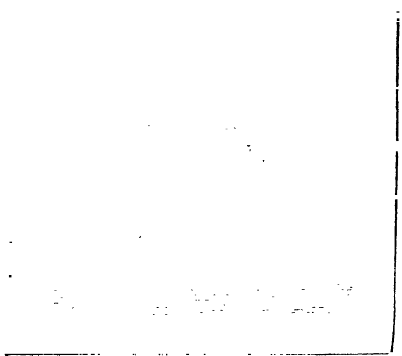
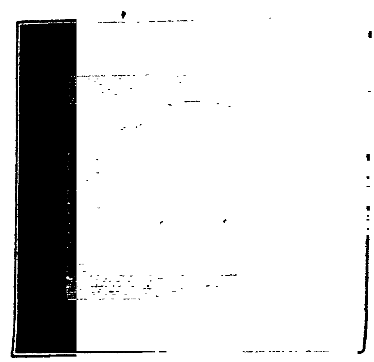


Fig. 128.



pans inverted so as to cover the glass; *d d* are small openings and pipes in the top of the covers, which communicate with the outside of the point of the kiln to carry off any vapors. The carriages are admitted into the kiln at the door *e e*, and when the door is closed, the heat reverberates within the arch, and passes off through the chimney *f*.

The carriages and beds are heated before they enter the kiln, so as to save time, and the more effectually to protect the glass from the smoke and fire, the edges of the covers are fitted into grooves cut into the stone beds, and carefully closed with powdered chalk, or some other suitable material.

By this arrangement the advantages of both the old plans are secured without their disadvantages.

Nothing certain can be stated with reference to the composition of enamel, as we possess no knowledge of the combination, the separation of which causes the opacity or turbid appearance of the cooling mass of glass. The analysis quoted at p. 26, corresponds with a glass containing 11 equivs. of silica, 5 equivs. of oxide of lead, 3 equivs. of potash, and 2 equivs. of oxide of tin, whence we can only deduce, that enamel contains more oxide of lead, and less silica, than any other species of glass that has been examined.

In the same manner as white enamel is obtained from colorless glass, so colored enamel may be produced from colored glass by the addition of enamel. A transparent glass pigment, burnt in upon ordinary enamel, also gives the appearance of a colored enamel, in consequence of the opacity of the back-ground. The latter process forms indeed the principal point in enamel-painting, the effect of which is calculated for reflected, and not for transmitted light. The colors are sometimes applied mixed with the flux, and at others are previously melted with it, if the coloring metal requires a higher degree of heat to enter into combination, than can be produced in the

enameling-furnace. In the former case, the pigment is a simple glass mixture, which is converted into glass by burning; in the other, it is a perfect glass, which is only melted on in the enameling-furnace. The pigment must, of course, be more easy of fusion than the enamel, and whenever several colors are burnt in, the upper or last must always be more easily fusible than those which have preceded it. The same furnace, however, which is shown at Fig 125, serves for all these operations.

It is now very common to coat the iron vessels used for domestic purposes with a species of enamel, which is done in the following way. The utensil is first washed with weak sulphuric acid, and then with cold water. It is now dipped in a mixture of

Quartz, previously fused with borax } in the form of an impalpable powder,
Felspar }
Clay, free from iron, and
with sufficient water to make a tolerably clear liquid.

The inside is afterwards dusted with a bag containing a mixture of felspar, carbonate of soda, borax, and a little oxide of tin, in the state of fine powder.

The utensil when dry is submitted to the proper heat in the enameling-furnace; the coating which results is very white, and resists the action of the fire, as well as that of acid and alkaline solutions.

Aventurine.—Under the name of aventurine, a species of colored glass was formerly manufactured at Venice, and adapted to ornamental purposes and trinkets, the appearance and properties of which were due to the same circumstances that occur in the mineral (a species of rock crystal) bearing the same name. It consists of an easily-fusible, brown, or in thin layers, yellow mass, enclosing numerous fine, yellow laminæ with a metallic lustre, which give a peculiar appearance to the whole. The common statements, that aventurine glass is produced by melting scales of metal or mica with the glass, are for this reason untenable, that under the microscope, these scales appear as regular three or six-sided tables, perfectly crystaline in structure. The mean of several analyses yielded Wöhler the following numbers:

Silica (with traces of oxide of tin)	65.2
Phosphoric acid	1.5
Oxide of copper	3.0
Oxide of iron	6.5
Lime	8.0
Magnesia	4.5
Soda	8.2
Potash	2.1
A trace of alumina with sulphuric acid	—
	99.0

Whence it follows that the mass is really an ordinary glass, remark-

ably deficient, however, in basic constituents, and which owes its other properties and its color to the copper (suboxide) which it contains.* The opacity of the laminæ is in favor of their metallic nature, and the similar appearance and crystaline form of the metallic particles obtained by the reduction of a salt of copper by means of phosphorous or sulphurous acid, render it probable that the brilliant scales in aventurine are minute crystals of metallic copper, produced by the addition of a powerful reducing agent to the melting cupreous glass. Perfectly similar scales have also been found in the slag from the copper-refining furnaces.†

Glass-Mosaic.—The difficult, and consequently rarely executed, glass-mosaics (better known as *millefiori*), presents a very peculiar appearance, which, inasmuch as it depends upon reflected light, resembles that produced by enamel-painting. Rome has always been the principal seat of this art, which must not be confounded with the glass-mosaic of the ancients, produced by the combination of discs of colored glass.

The material for these works of art consists of a number of thin rods, half an inch in length, composed of very easily-fusible glass of all possible colors and tints, which are prepared in manufactories erected specially for this purpose. Masses of colored glass are prepared in these manufactories, from which a kind of cake is formed; this is then converted, by the peculiar manipulation of the workmen with the aid of a sharp hammer and an anvil, first into slabs and then into the little rods mentioned above. In this form the material is supplied to the artist, who softens it in the flame of a lamp, and draws out each rod into a thick thread, and breaks off a piece of the thickness of the intended picture. These pieces are then arranged one after the other, according to the design on a cartoon, on a slab of copper covered with a layer of cement, which serves for the reception and fixing of the picture. When the whole slab is covered, the sur-

* Compare Peligot's Analysis of Venetian Aventurine, given at page 26.

† It has often been a matter of some difficulty to account for the existence of colored glasses amongst the ancients, when we know that they were totally unacquainted with the chemistry of the metals, and their combinations, &c. The difficulty is most satisfactorily solved by the observation of Knox, who found that all the metals, with the exception of platinum, are dissolved as such by melting glass and impart color to it, if the heat necessary for combination is kept up for a sufficient length of time. Similar observations have been made, generally by chance, in glass-houses. Knox has shown that lead and copper are dissolved in small quantity; tin, antimony, and bismuth, with greater ease, and iron the most readily of all the metals. Gold imparts a green color in the first instance, which subsequently becomes purple, and of a darker hue the more silica there is in the glass.

In one of the Roman tombs which were discovered in constructing a road, some fragments of a beautiful white glass vessel were found, which were remarkable for their great weight. Girardin found that the glass contained a considerable quantity of lead and some copper. The manufacture of lead-glass appears, therefore, to have been known to the ancients, although they make no mention of it. Another blue glass, from an Etruscan tomb, was found to contain cobalt, and this metal was also shown by Davy to be the coloring oxide in an antique blue glass. The ancients, it appears, looked upon cobalt as a species of copper, an error which was first exposed by G. Brandt, in 1742. Another blue glass, found in France, was, on the contrary, colored with the cæruleum of Vitruvius.—*Chem. Gaz.*, v. 199.

face, which is uneven and unsightly from the unequal lengths of the little rods, is ground and polished. After the removal of the polishing powder, the interstices between the rods are filled with wax, which must correspond in color with the different parts of the picture. The largest known mosaic painting, taken from the Lord's Supper of Leonardo da Vinci, which is twelve feet high and twice as long, occupied the time of eight or ten artists daily during eight years.

There yet remain a few mechanical manipulations and curiosities in the art of glass-making, which are interesting in several points of view, and require some explanation.

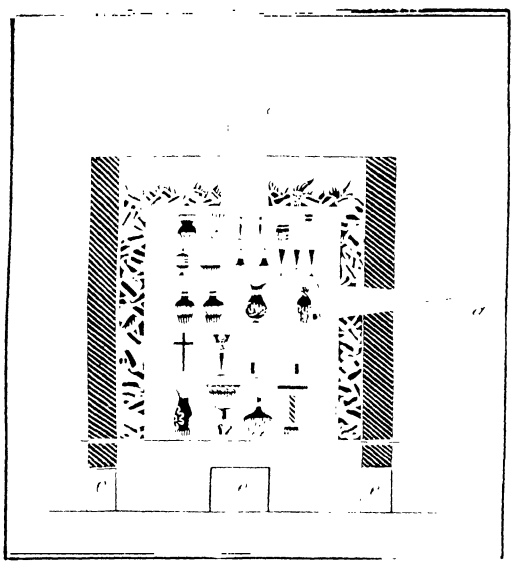
Incrustations in Glass.—When a transparent fluid rests upon a rough surface which is not moistened by it, a layer of air is included between the two, which causes the under surface seen through the fluid to appear like dull silver. This phenomenon may often be witnessed when drops of rain remain upon the woolly leaves of certain plants; indeed, this simple observation first incited an ingenious glass manufacturer of Bohemia to endeavor, with proper means, to obtain the same effect in glass. The result of his endeavors came up to his expectations, and the invention has since been called that of the *glass-incrustations.* The best material for the rough surface are impressions taken in pure burnt pipe-clay, biscuit porcelain not answering so well, as it is less porous. Care must be taken in drying and burning these impressions, in order that the peculiar porosity and roughness of the surface, upon which everything depends, be not impaired. When a cast of this kind is pressed into a soft mass of glass, another layer of glass poured over it, and the whole exposed to the heat of the furnace until proper contact has been effected, the glass appears to attach itself intimately to the clay, but in reality a thin stratum of air is enclosed between the two, which, on looking through the ground and polished surface of the glass, gives the white cast the most perfect resemblance to dull silver. If the glass is colored of the proper yellow tint, the appearance of dull gold is produced. Actual bubbles of air must of course be carefully excluded by the workman, and this is not very easy when the glass is refractory. These beautiful ornaments can be incorporated in any glass vessel, provided the glass is of sufficient thickness.

Gilding.—Vessels which are not often used, and are not liable to wear, may easily be gilt by fixing leaf gold upon them with copal-varnish. Real gilding is, however, much more durable, and is effected by the aid of heat. For this purpose, a solution of gold in aqua regia (chloride of gold) is precipitated by potash or green vitriol, when a very finely divided brown powder, consisting of metallic gold, is obtained; this is washed, and dried, and rubbed up with a proper flux, *e. g.* anhydrous borax (vol. i. p. 310). This mixture is then easily applied with a brush, having been previously mixed with oil of turpentine or gum-water. When the dried pieces are now heated in the muffle, the volatile oil escapes, the gum is consumed, and the borax melts and firmly attaches the gold dust to the surface of the vessel.

Fig. 129 represents the muffle and furnace of M. Bastenaire

Daudenart, used for firing the gilded vessels. The interior is composed of iron-plate, with a lid and chimney *c*; the whole of this iron muffle is surrounded with red-hot coals; *e e* are apertures for affording

Fig. 129.



air to keep up the combustion; *a* is an aperture through which small samples can be introduced, by means of which the heat can be regulated. The pieces are placed upon sheet-iron shelves.

Dumas remarks, that the heat in this muffle must be considerably higher in the upper part than in the lower, and that an ordinary muffle-furnace would probably afford a greater uniformity of temperature.

The gold is dull, yellowish-brown and without lustre when first removed from the fire, but acquires lustre and its peculiar color by the friction of a burnisher made of agate or blood-stone.

Silvering.—Silvered glass is not remarkable for beauty, and is seldom seen; silver, precipitated from solution by copper, can, however, be applied to glass, and burnt in, as was the case with gold, or glass may be silvered in the manner already described under plate-glass.

Coppering.—According to R. Mallet a copper surface can be given to glass by galvano-plastic agency, of so great tenuity, that 1 grain of copper covers about 90 square inches of surface. The surface of the glass is coated with turpentine or Canadian balsam, and powdered graphite is strewn over it; one end is then connected with a copper wire, and the whole is plunged into the solution of sulphate of copper in the galvano-plastic apparatus; in a few hours it is covered with a close stratum of copper, which is well adapted for chemical purposes, but not for ornament.

Dr. Elsner has proposed to accomplish this object by a slight modification of the method recommended by Dr. Mohr. He dissolves 2 parts of asphalte and 1 part of mastic in turpentine, and applies this varnish reduced to the consistence of a syrup, by means of a brush, to the surface of the earthenware vessel. While the varnish is still soft, finely pounded graphite is sprinkled over the whole surface, so as to render it a good conductor. The vessel is now suspended in a concentrated solution of sulphate of copper, and connected with the zinc pole of a Daniell's battery. A strip of copper inserted in the vitriolic solution is connected with the copper pole. The vessel is soon coated with a layer of copper possessing the beautiful red color of this metal when reduced by electricity, and is so hard and adhesive as to be capable of receiving a polish.

When glass or porcelain vessels are to be coated, the above process is modified in the following way. The surface of such vessels is exposed to the action of the vapors of fluoric acid, until it becomes sufficiently corroded to retain the sprinkling of graphite powder, when the coppering may be commenced as described in the case of earthenware or unglazed vessels. The use of varnish is dispensed with, as the graphite adheres to the rough surface.

The above process might be advantageously applied to the coating of unglazed vases and ornaments for gardens.

Platinizing.—The same process is practiced for coating glass with platina, which is precipitated directly from solution upon the glass, but it is not so applicable as in the case of gold. According to Döbereiner, an alcoholic solution of chloride of platinum ($PtCl_2$) is evaporated to dryness, the dry mass is redissolved, and again evaporated until the residue is no longer precipitated by a solution of sal ammoniac, and is completely converted into the chloroplatinate of chloride of acetyl ($C_4H_3Cl+PtCl$). When glass is coated with a solution of this compound, and heated (over a spirit lamp, for instance), the platinum is precipitated as a metallic mirror over the whole surface.

Ludersdorff recommends the following mixture for platinizing glass or porcelain.—4 parts of chloride of platinum dry, 4 parts of alcohol of 95 to 96 p. c. are slowly mixed with 5 parts of oil of lavender. The platinum is contained in this solution in the state of protochloride, held in solution by the hydrochloric and acetic acids which are produced. This is painted with a brush upon the vessels, and they are then exposed in the muffle to a dark-red heat (for stoneware and easily fluid glass) for half an hour; if a lower temperature is employed, the reduced platinum does not adhere to the vessels; if the temperature is higher, the lustre of the platinum is diminished—with porcelain and hard glass a bright-red heat may be given; but as soon as this is attained, the heat must be moderated. The lustre is at last brought out by friction with wool and wet-chalk-powder. Glass mirrors thus obtained are said to be very perfect.

Reticulated Glass.—Amongst the most beautiful ornamental productions of old Venetian art, are the so-called *reticulated glasses*, produced by a kind of net-work, consisting of small bubbles of air,

enclosed within the mass, and ranged in regular series, crossing and interlacing each other. The art of preparing these glasses was lost for a long period, but has been again revived by Pohl. In order to produce this ornamental appearance in any part of the glass vessels, hollow glass cones or conical tubes are kept at hand which already contain this net-like arrangement of air-bubbles, and can be inserted at any part of the vessels, for instance, in the stem of wine-glasses, &c. The chief thing, therefore, is the manufacture of these tubes, which are made by arranging a number of small narrow glass rods round a centre, so as to form a cylinder, and fixing them in this position by melted glass. The hollow cylinders are then heated until the single rods stick together, when they are drawn out on the pipe to a long cone, and spirally twisted at the same time, the one half to the right and the other to the left. When one of these hollow cones is inserted into the other, and the two are heated until they fuse together, wherever the little rods cross each other a bubble of air will be enclosed, and this will occur in a very regular manner, and produces, indeed, the reticulated appearance.

Glass Beads.—Besides the invention of mirrors and reticulated glasses, for which we have to thank the Venetians, the art of making glass beads was also first discovered in the glass-houses of Murano, and is practiced there at the present day, on a very extensive scale. The small glass beads are fragments cut from pieces of tubing, the sharp edges of which have been rounded by fusion. Glass tubes of the proper size are first drawn from 100 to 200 feet in length, and of all possible colors (in Venice they prepare two hundred different shades), and are broken into lengths of two feet. These are then cut by aid of a knife into fragments of the same length as their diameters; they now present the form of beads, the edges of which, however, are so sharp, that they would cut the thread upon which they have to be strung. The edges have consequently to be rounded by fusion, and as this operation must be performed upon a great number at once, and they must not be allowed to stick together, they are mixed with coal dust and powdered clay, previous to being placed in the revolving cylinder in which they are heated.* The finished beads are then passed through sieves, sorted according to their size, and strung upon threads by women. Besides the ordinary knitting beads, another kind is manufactured, called *perles à la lune*, which are firmer and more expensive. These are prepared by twisting a small rod of glass softened by a glass-blower's lamp round an iron wire.

The glass beads made in imitation of natural pearls for toilet ornaments, the invention of which dates from the year 1656, are very different from the preceding, both as regards their application, mode of production, and origin. These are small solid glass beads of the same size as native pearls, which they are made to resemble by a coating of varnish, and which gives them a peculiar pearly lustre and

* Sand and wood-ashes are also stirred together with the beads before heating them, that the perforations may be filled by the sand, and the sides thus prevented from falling together in the subsequent process.

color. A maker of rosaries, by name Jacquin, was the first to discover that the scales of a species of fish (*Cyprinus alburnus*), or *bleak*, communicate a pearly hue to water. Based upon this observation, glass globules were first covered on the outside, but at a later period, on the inside, with this aqueous essence; the costly essence, however, of which only ¼ lb. could be obtained from the scales of 4000, was subject to one great evil, that of decay. After trying alcohol without success, in consequence of its destroying the lustre of the substance, sal ammoniac was at length found to be the best medium in which to apply the essence; a little isinglass is also mixed with it, which causes it to adhere better. The pearls are blown singly at the lamp, a drop of the essence is then blown into them through a thin tube, spread out by rolling, and the dried varnish is then covered in a similar manner by a layer of wax.

When the inner surface of the glass pearls is covered in this manner with colored wax instead of the essence, the well-known glass corals are produced, which, with the larger kinds of glass pearls have proved of no small importance as articles of barter or commerce with savage nations.

Glass spinning.—The excessive pliability of softened or melted glass admits of a drop being extended in the form of a thread of incredible length and of almost immeasurable fineness. The drawn-out end of a glass rod has only to be attached to a revolving-drum, whilst the rod whence the thread proceeds is held in the glass-blower's lamp, in order to obtain in a few minutes several ells of spun glass. The thread possesses of course the color of the glass, but its tenuity is so great that the color is scarcely perceptible, unless very deep shades have been employed. Viewed in mass, spun glass exhibits a very brilliant lustre, far exceeding that of silk, and it is of course very much more durable. These properties, as well as the low price of glass, naturally suggested to manufacturers the advantage of making it a material for spun fabrics. The attempts which have been made in that direction, have not, however, met with success; although it was found applicable to unimportant ornamental articles, such as girdles, feathers, &c. Great difficulties presented themselves, when an attempt was made to convert it into stuffs for clothing in the loom. The object to be achieved consisted in producing the threads of such uniformity and firmness, that they did not break when bent at a very sharp angle. Glass, as it is usually spun, is liable, when woven, to break in a great number of places, and sharp prominent points are thus exposed which excite the skin in a very unpleasant manner. This branch of manufacture has nevertheless been revived with success by Olivi, Dubus-Bonnel and Bouillon. Dubus more particularly has succeeded, by means of steam as it is stated, in producing glass thread that can be knotted and woven into fabrics on Jacquard's machine, which are equal in every respect to the most beautiful gold and silver brocade. The particulars of this branch of manufacture have not yet been made public.

Etching in glass.—It has already been noticed among the general

properties of glass, that it is energetically attacked and rapidly decomposed by hydrofluoric acid only. One portion of the silica is carried away in this process with the fluorine, as fluosilicic acid gas ($SiFl_3$), whilst the remainder is left with the other constituents of the glass as a flocculent powder on the part eaten away, whence it can easily be removed. This process has long been used as a means of etching on glass, and is accomplished by covering those portions of the glass that are to remain unacted upon by the acid, with some substance that is not affected by it, whilst that portion of the vitreous surface on which the letters, figures, &c., are to be engraved is freely exposed to the chemical agent. Wax is used as the etching-ground, or better, a mixture of asphaltum, mastic, and some oil of turpentine, with which the warm glass is uniformly coated, and the drawing then executed with a needle. The point of the needle removes the ground on one side, and exposes those parts of the glass which it traces to the action of the acid. When fluoride of calcium (CaFl) is now covered with concentrated sulphuric acid in a leaden vessel and gently warmed, hydrofluoric acid vapor is evolved, by reason of the exchange of calcium for hydrogen in the fluoride of calcium, while sulphate of lime (CaO,SO_3) and hydrofluoric acid (HFl) are produced. In a few minutes the uncovered portions of the surface of the glass which has been held over the leaden vessel, are found as deeply etched as in an engraved copper plate, and the etching is deeper in proportion to the time the glass has been exposed to the vapors. It is thus possible to produce gradations in the amount of etching by covering the less deep portions after the first exposure with etching-ground, and exposing the others a second time to the vapors. Glass may be etched equally well by surrounding it with a rim of wax, and covering it with a solution of hydrofluoric acid. When the etching is finished, the etching-ground is cleaned from the glass by heat and washing with oil of turpentine. The scales on thermometer tubes, inscriptions on glass vessels, &c., are thus advantageously and indelibly fixed.

The possibility of etching upon glass soon led to the idea of making it subservient to typographical uses in place of copper plates or stone; ink laid on to an etched glass plate will necessarily remain in the concavities and produce an impression upon paper that is pressed upon the plate. The hardness of glass adapts it particularly for this purpose, and, when compared with copper, it is scarcely injured at all by use, and there is no possibility of the etched lines merging one into the other under the press; a vast number of impressions may consequently be taken from the same plate, and this can be made by the artist in the same number of days, as months would have been occupied in preparing a copper plate. But very serious objections interfere with this application of glass. In the first place, the brittleness of the glass renders the plates liable to break under the rollers; the effect of the hydrofluoric acid vapors to which the workmen are exposed is very injurious, and lastly, there is no possibility of mending or remedying any lines that may have been too deeply etched,

which in the case of copper plates is easily done by forcing the edges together with the polisher. The first difficulty was soon overcome by cementing the plate of glass into a frame work, or upon a strong plate of cast iron. The glass cannot then be broken, as no portion is unsupported; it cannot therefore be bent, and the force of the press will only tend to crush the glass, and for this it is totally insufficient. Latterly the use of glass in typography (hyalography) has been revived by Bromeis and Böttiger, who assert that they have conquered all the difficulties, by employing a new method and means of etching, which is not in the least injurious to the workmen, which requires no heat in its application, and gives rise to no gases or vapors; they prevent the breakage of the plates by a method similar to that already described. The etching substance is also said to be of such a character, that the same quantity may be used one hundred times without perceptibly losing any of its original power. The inventors also maintain that the etching may be re-touched or improved with facility at any part without injury to the rest of the drawing; but this appears in direct contradiction to all the known properties of glass. The impressions are very sharp and clean, and in this respect unobjectionable, but they appear remarkably stiff and hard; although this property may possibly exclude the use of glass for purposes of art, it renders it very appropriate for engraving maps, visiting cards, bank notes, and the like.

Bedford has patented a peculiar process for etching glass, which consists in grinding 5 parts of puce-colored oxide of lead (peroxide), and 1 part of flux (the flux employed being composed of 17 parts glass of borax, and 13 parts of red-lead fused together) with turpentine; with this composition the artist paints the devices or designs upon the surface of the glass to be etched. If colored glass is to be etched, acetate of lead is substituted for the oxide of lead above. The vessels are then dried and fired in the same manner as in gilding glass (See Fig. 129). When cold, the vessels are dipped in a weak solution of nitric acid, and as soon as the painted designs are acted on, the articles are placed in water, and the preparation is removed from their surfaces.

Cast-Glass Plates as Ventilators.—Mr. Lockhead has recently secured a patent for preparing perforated sheet or plate-glass, which he applies to the purposes of ventilation in rooms, walls, ships' sides, &c.

Fig. 130 shows the manner in which it is proposed to adapt these plates to the top of a common window; the sash being down, the air enters through the apertures in the fixed perforated plate. Fig. 131 represents a square of glass with a round ventilator in a frame, for buildings, &c. These perforated plates are prepared in the same manner as plate-glass, the metal being poured upon a casting-table from the pot, in a liquid state, and rolled out in the first instance by an ordinary smooth roller. While the metal is still in the soft pasty state, a second roller, with projections upon its surface, is either passed over the glass, which cuts the holes in its passage, without injuring the casting-table below; or moulds, with projections having the shape

Fig. 130.

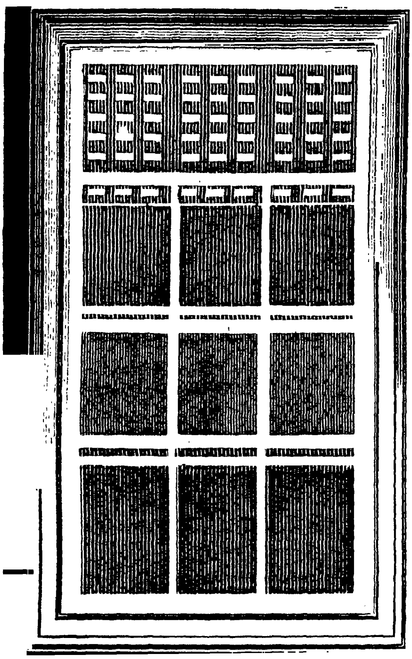
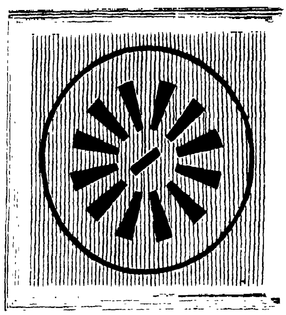


Fig. 131.



of the future holes, are pressed down upon the soft metal, and removed as soon as the latter has become solid. The plates thus perforated are subsequently annealed, ground, and polished in the usual manner.

Metallic Letters fixed on Glass.—A novel application of brass letters to the surface of panes of glass, by means of a cement, has been very recently introduced by M. Lamenaude. The cement with which these metallic letters are attached to the vitreous surface, is composed according to one or other of the following recipes:

Copal varnish	15	Dissolved in a water bath and mixed with 10 parts of hydrate of lime.
Drying oil	5	
Oil of turpentine	3	
Essence of turpentine	2	
Animal glue	5	

Sandarach and galipot resin varnish	15	Mixed together and incorporated with 10 parts of Spanish white and dry white lead.
Drying oil	5	
Oil and essence of turpentine	5	

Copal varnish and gum lac, mixed	15
Drying oil	5

Solution of caoutchouc or gutta percha - - -	3
Tar oil - - - - - -	7
Roman cement and plaster of Paris mixed in powder -	10

Or,

Copal varnish and colophany resin - - -	15
Oil and essence of turpentine - - - -	5
Isinglass in powder - - - - -	2
Iron filings or blacksmiths' cinders ground and sifted -	3
Washed earth, ochre, or rottenstone - - -	10

Glass Boring.—It is often necessary for practical purposes to bore holes in glass, and this operation, in consequence of the hardness of glass, is not unattended with difficulty. It will be found advantageous for this purpose to moisten the points of the steel instruments, drills, &c., with a little oil of turpentine in which some camphor has been dissolved; the glass is then found to work with much greater ease, and holes of any size can be bored.

SOLUBLE GLASS.

The silicates of the alkalies which are not mixed with any proportion of earthy silicates are of practical importance in a very different point of view from ordinary glass. When silica is fused with an excess of carbonate of potash, the oxygen of the carbonic acid that is expelled is precisely equal to that of the silica which replaces it in combination with the soda; a combination of 3 eqs. potash with 2 eqs. silicic acid is produced, which is remarkable for its deliquescent property, and which, when dissolved in water, is known as soluble glass (*liquor silicum*). This liquid can also be obtained by dissolving precipitated silica in caustic potash.* The same degree of solubility is exhibited by the less basic compound discovered by Fuchs, called *soluble glass*, which contains 3 eqs. of potash to 8 of silicic acid, and this is of more importance in the arts, as, although soluble in hot, it is very little soluble in cold water, and consequently is not deliquescent. Soluble glass may be obtained in a purer form by completely saturating a solution of caustic potash with precipitated silica, and evaporating the solution; or more economically and sufficiently pure for technical purposes, in the following manner: 15 parts of powdered quartz or pure sand are melted with 10 parts of potashes, and 1 part of charcoal, in a crucible, until complete vitrification occurs. The charcoal is here employed to aid in vitrifying the potash by decomposing the sulphuric acid, and also the carbonic acid into carbonic oxide ($CO_2+C=2CO$). The mass of glass is difficult of fusion, hard, filled with bubbles, and of a grayish-black color; when the potashes are not pure, foreign salts are introduced into the mixture, as chloride of potassium, carbonate and sulphate of potash, and more particularly

* That a soluble silicate could be obtained by treating powdered glass with caustic ley, which deposited silica on the addition of an acid, was known to Van Helmont, according to Kunkel.

sulphuret of potassium, which is very objectionable on account of the disagreeable odor which it occasions. These substances, however, are easily separated by pulverizing the mass, and exposing it to the air. Entire pieces attract moisture on their surface under these circumstances, and cracks appear, but they are not essentially altered; the powder, on the other hand, is so hygroscopic, particularly when it is frequently turned over, that the foreign salts are readily dissolved and carried away by the water. In this state the whole is treated with cold water, in which these salts dissolve completely, and the soluble glass which remains is thoroughly washed with water. The purified mass is now boiled with 5 parts of water, in which it slowly but entirely dissolves. The dilute solution is rather quickly decomposed by the carbonic acid of the atmosphere with the separation of silica, and the solution for technical purposes must consequently be evaporated until it attains a specific gravity=1.25. In this salable state, the glass forms a sticky, syrupy, somewhat turbid liquid, which throws up a scum when boiled that can be re-dissolved. It easily gelatinizes on cooling, and dries up when exposed to the air, without perceptibly absorbing carbonic acid, in the form of a clear, transparent, colorless, brittle, but not very hard glass, containing 26 per cent. potash, 62 per cent. silica, 42 per cent. water. This glass has an alkaline taste and reaction, as has also the solution; it is, itself, inalterable in the air, but when exposed, its surface becomes covered with an efflorescence of foreign salts, which can be removed by cold water. The solution of the glass is miscible in all proportions with water, but is precipitated unchanged* by alcohol.

Soluble glass may be more advantageously prepared, on account of the greater purity of the product, and with the same facility, by fusing together 1 part of quartz with 2 parts of crystalized soda. Although the composition of this product is different, it contains 2 equiv. soda to 3 equiv. silicic acid, yet the mode of preparing it is the same, and its properties resemble those of the potash glass. When soda and potash both enter into the composition of the glass (15 quartz, 5 potashes, 4 dry soda) the mass is rendered more easy of fusion, as the simple silicates of soda and potash are more refractory than the mixed silicates.

The chief application of fusible glass is for coating combustible substances, as wood, stuff, paper, &c. It diminishes the inflammability of these bodies by forming, when dried upon them, a layer of glass that impedes the free access of air, and thus removes the most essential condition for combustion. Wood covered with fusible glass and held in a flame, is in the same condition as wood in a charcoal furnace. It is subject, in the first instance, to the decomposition caused by heat alone, or to dry distillation. Combustible gases are evolved, the combustion of which cannot of course be prevented by the coating of glaze. The layer of glass being very thin, it will naturally soften with the heat, and swell; the gases will at last burst

* This statement is made by Fuchs; but Forchhammer found the precipitated salt composed of $3KO,16SiO_3$.

the coating, and eventually the wood itself, the interior of which being then freely exposed to the air, must necessarily burn, being no longer protected by the glaze. It must, therefore, not be supposed that soluble glass renders these substances incombustible, its use is confined to rendering them less susceptible of taking fire. Soluble glass exerts no injurious action on the substances to which it is applied, it covers well, and forms a perfectly transparent varnish; it is preferable, for these reasons, to other substances, such as clay-water, which is also used to diminish the inflammability of combustible bodies. In order to produce a permanent covering, it should not contain any large amount of foreign salts, which would effloresce on the surface; and the first coat that is applied must be very dilute, in order to penetrate the substance of the material before the subsequent coats are laid on. Every layer should be allowed to dry for 24 hours before a fresh layer is given; if this precaution is not observed, the whole is liable to crack and peal off. The tendency to crack and peal off is not so prominent in soluble soda glass, as in the other varieties.

Soluble glass is still more serviceable when it is not applied alone, but with some other pulverulent substance as a body, in which case it plays the part of a cement. Ordinary glass powder, or that of crude soluble glass, chalk, slag, bone-earth and clay, may all be used for this purpose. In the Theatreat Munich, where 465,300 square feet of wood surface was coated with soluble glass, it was found advantageous to mix it with $\frac{1}{10}$th of ferruginous clay. It must not be overlooked that a chemical decomposition frequently accompanies the use of these substances with soluble glass. The alkaline salts, (particularly the carbonates, chlorides, and most of all, sal ammoniac) produce a gelatinous, pasty precipitate in solutions of soluble glass; sal ammoniac also evolves ammonia. The salts of the earths produce precipitates containing potash, the earth and silicic acid; alumina exerts a like action, and similar insoluble compounds are formed by the addition of the alkaline earths (for instance, by hydrate of lime). A portion of potash is in every case separated from the soluble glass, which either takes no part in the formation of the precipitate, but remains free in the solution, as in the last case, or combines with the acid of the salt which has been added. The same applies to the salts of the heavy metals, *i. e.* iron and copper. Nor is the action of soluble glass less energetic upon different insoluble, or very difficultly soluble salts, for instance, sulphate, carbonate and phosphate of lead, phosphate of alumina, gypsum, &c., which, when rubbed up with soluble glass, all form pasty masses, that become hard like stone on exposure to the air, in consequence of the mutual decomposition which ensues.

Dry powdered soluble glass has proved a very beneficial addition to a solution of the same substance, whilst oxide of lead under the same circumstances affords a mass that contracts very much, and easily peals off; $\frac{1}{14}$th of lead as an addition to soluble glass has only been found applicable to linen or woven cloth, the texture of which admits of its yielding with the contraction. Simple immersion of the

cloth in the solution has not been found to suffice, but pressure (between rollers for instance) must be employed, in order thoroughly to impregnate the fibre of the cloth with the solution. Impregnated in this manner, the cloth can be rolled up when dry, but cannot be folded.

Soluble glass may be employed as a paint in rooms, the walls of which have been previously coated with a mixture of sand, clay, and soluble glass. Coatings of this kind preserve a remarkably fresh color, and can be washed with water from time to time. It must, however, be observed that many colors, as Prussian-blue, vegetable lakes, &c., are changed or destroyed by the alkaline reaction of the soluble glass when brought into immediate contact with it.

Soluble glass may also be employed as a cement for glass and porcelain vessels, and excels most other matters that are used for the same object.

Lastly, Kuhlmann has recently called attention to the fact, that pieces of chalk or gypsum, or objects composed of these materials, may be easily silicified by impregnating them with soluble glass and exposure to the carbonic acid of the atmosphere. This silicification penetrates a considerable depth into the mass, and even when only 3 or 4 per cent. of silica has been taken up, communicates a degree of hardness to the objects, which is comparable with that of marble, and renders them capable of taking a fine polish.

THE MANUFACTURE OF ALUM AND VITRIOL.

OF ALUM.

Definition.—The term alum is applied scientifically and collectively to a number of double salts, which are composed of very different proximate elements, arranged, however, in the same manner. The constitution of these salts may be expressed by the general formula $MO,RO_3+M_2O_3,3RO_3+24$ aq. in which R represents the radical of the acid, and M the metallic salt basyle. Alums are known in which the acid is chromic acid (CrO_3), in others it is sulphuric acid (SO_3); some contain potash (KO), in place of MO in the general formula, others soda (NaO), and, again, others oxide of ammonium (NH_4O); the base, M_2O_3, may be at different times oxide of iron (Fe_2O_3), alumina (Al_2O_3), or oxide of chromium (Cr_2O_3). In consequence of the power which these different bases and acids possess of replacing each other in variable proportions, some only, or several of them may take part in the formation of one and the same crystal of alum; in every case, however, the crystal will contain 24 equivs. of water of crystallization.

Commercial Application.—Two of these compounds only are applied in the arts, and these are composed of sulphate of alumina in combination with sulphate of potash, or sulphate of ammonia, or both together, $\left(\begin{matrix}KO\\NH_4O\end{matrix}\right\}, SO_3+Al_2O_3,3SO_3+24aq.)$ Potash-alum is simply called "alum" amongst practical men, whilst the other variety is distinguished by the name of "ammonia-alum." Both are of equal

value for manufacturing purposes. These bodies are mainly used in the arts for the alumina which they contain, and the sulphate of potash and water of crystalization are in themselves superfluous. The possibility, however, of producing a cheap and pure salt of alumina in large quantities is dependent on the property which alum possesses of crystalizing in large crystals, and this quality of purity in the salt, renders it worth the manufacturer's while to pay for the water and alkaline sulphate in the compound. In fact, sulphate of alumina is soluble in 2 parts of cold water, and is consequently very difficultly separated from the other extraneous salts, particularly from sulphate of iron, which accompany it in the process of manufacture, whilst alum, on the contrary, from the ease with which it dissolves in hot water and its slight solubility in cold, is easily separated from any deleterious substances of that kind; 1 part of crystallized alum at 12°.5 C. (55° F.) requires 13.3 parts of water to dissolve it, at 87°.5 C. (190° F.), however, only 0.06 parts.

Native Alum.—Alum, like saltpetre and carbonate of soda, occurs as an effloresced salt, and is met with in volcanic districts in the form of a white floccular covering, produced by the action of sulphuric acid vapors upon lava and trachyte substances containing alumina and potash, in a similar manner to that in which artificial alum is obtained. In this form it occurs in Auvergne in the south of France, in Sicily and the volcanic islands on its northern coasts, but more particularly in the neighborhood of Naples, in the Grotta di Alume (on Capo Miseno), and in the Solfatara.

The effloresced salt is collected in these localities, dissolved in water, and allowed to deposit the insoluble matters by standing. The clear solution affords on evaporation an impure alum, which is recrystalized, and brought into commerce as a very pure product. No fuel is used for the evaporation, but the natural volcanic heat of the soil (40°=104° F.) in which the leaden pans are imbedded. Native alum forms, however, a very small portion of that which is consumed in Europe.*

The following is the composition of some of these natural alums.

SODA- AND AMMONIA-ALUM.

Constituents.	From Rio Saldana. Andes.	Soda Alum from South America.		Ammonia-alum from Tschermig.		
	Thomson.	Thomson.	Gruner.	Pfaff.	Lampadius	Stromeyer.
Sulphuric acid	35.872	37.7	33.682	36.00	38.58	36.065
Alumina - -	14.645	12 4	10.750	12.14	12.34	11.602
Soda - -	2.262	7.5	"	"	"	"
Silica - -	0.100	"	"	"	"	"
Lime - -	"	"	"	"	"	"
Protox. iron -	"	"	3.619	6.58	4.12	3.721
Perox. iron -	0.500	"	"	0.20	"	0.115
Water - -	46.375	42.4	51.000	45.00	44.96	48.390
	99.754	100.0	99.051	99.92	100.00	99.893

MANGANESE AND MAGNESIA ALUMS.

Constituents.	Algoa Bay,* South Africa.	Bosjesmans River,* South Africa.	Iquique, South America.
	Apjohn.	Stromeyer.	Hayes.
Sulphuric acid - -	32.79	36.770	36.332
Alumina - - -	10.65	11.515	12.130
Magnesia - - -	"	3.690	4.082
Protoxide of manganese -	7.33	2.617	} 0.430
Protoxide of iron - -	"	"	
Lime - - - -	"	"	0.126
Sulphate of magnesia -	1.08	"	"
Chloride of potassium -	"	0.205	"
Muriatic acid - - -	"	"	0.604
Water - - - -	48.15	45.739	45.450
	100.00	100.536	99.754

IRON ALUMS.

Constituents.	Unknown.	Hurlet.	Mörsfeld.	Iceland.	Puzzuoli.		Hurlet.	
	Berthier.	Phillips.	Rammelsberg.	Forchhammer.	Dufrenoy.	Abich.		
Sulphuric acid	34.4	30.9	36.025	35.16	45.67	48.32	- -	35 950
Protox. iron -	12.0	20.7	9.367	4.57	28.69	11 60	- -	"
Perox. iron -	"	"	"	1.23	"	17.65	- -	18.236
Alumina -	8.8	5.2	10.914	11.22	3.27	2.20	- -	"
Potash - -	"	"	0.434	"	5.47	4 04	Ammonia	3.653
Soda - -	"	"	"	"	"	0.25	- -	"
Magnesia -	0.8	"	0.235	2.19	"	"	- -	"
Sand - -	"	"	"	"	0 46	"	Impurities	3.500
Water - -	44.0	43.2	43 025	45.63	15.77	15.94	- -	38 661
	100.0	100 0	100.000	100.000	99 33	100.00		100.000

Production of Alum from Alum-Stone.—Alum is obtained in much larger quantity from *alum-rock*, a formation of similar volcanic origin. This is a massive, granular, only partially crystaline, transparent, and not homogeneous rock, which frequently encloses quartz, sometimes iron pyrites, and manganese ore. Its color is yellowish, passing into green, gray, red, or brown. The pure mineral *alum-stone* (*Alunite*) sometimes occurs in it in distinct crystals, which have been found to consist of a basic sulphate of alumina with sulphate of potash (a basic alum therefore); or, more probably, a combination of neutral sulphate of alumina and potash with hydrate of alumina ($KO,SO_3+Al_2O_3 3SO_3 + 2Al_2O_3,HO_3,$) (Rammelsberg); it differs, therefore, from alum in containing an excess of alumina. Alum-rock is of the same nature, but of a less pure character; it is a massive alunite, and occurs at Tolfa, near Civita-Vecchia, in the Papal States; at Montione, in the

mention of a remarkable lake, the water of which contained alum in solution. A recent exploring party on the Indus, have also reported the discovery of beds of alum and rock-salt below Attock.

* The alums analyzed by Apjohn and Stromeyer are the same: they cannot be regarded as chemical compounds, as no two analyses agree, and in situ, they are much mixed with efflorescent salt. As a mordant, the properties of the manganese-alum have been found by Mr. Crum quite equal to common alum, the manganese interfering in no way with the most delicate colors. This alum is used by the natives for dressing skins.

Dukedom of Piombino; in the Comitats, Beregh and Zemplin, in Hungary; at Mont d'Or, in France, and in the Greek islands, Milo and Nipoglio, but is not of very common occurrence.

The analyses of this rock have yielded the following results:

	From Tolfa, by Klaproth.	From Beregszaz, by Klaproth.	From Montione, by Descotil.	From Mont d'Or, by Cordier.
Silica	56.5	62.3	—	28.4
Alumina	19.0	17.5	40.0	31.8
Sulphuric acid	16.5	12.5	35.6	27.0
Potash	4.0	1.0	13.8	5.8
Water	3.0	5.0	10.0	3.7
Oxide of iron	—	—	—	1.4

It will be seen from these analyses, that, taking no account of the silica, there is chiefly a deficiency of potash, and also of sulphuric acid in the rock, in order to convert it into alum, or in other words, in the mineral from Tolfa, for instance, there is about 3 per cent. too much sulphuric acid and 14 per cent. too much alumina to form alum with the 4 per cent. of potash. The alum-stone from Beregszaz also contains an excess of 9 per cent. acid, and 16 per cent. alumina; that from Mont d'Or, 6 per cent. acid, and 25 per cent. alumina. At Tolfa, where the alum-stone comes to the surface, a quantity of alum is produced proportionate to the amount of potash in the rock, and the remainder, particularly the excess of alumina, is separated. This is effected by burning the stones in heaps or furnaces similar to those used in preparing gypsum (*see* below), particular care being taken that the temperature does not rise too high. At a red heat, sulphate of alumina is decomposed, yielding, partly anhydrous sulphuric acid, and partly oxygen and sulphurous acid. As soon as these vapors appear, the burning is stopped and the mass is transferred to walled cisterns, where it is repeatedly moistened with water, which collects below, and allowed to crumble for three or four months, at the expiration of which period it is converted into a soft mud, tasting perceptibly of alum, which may then be dissolved out with water. If the alum-stones contained an excess of hydrate of alumina, this would infallibly react upon the alum, and form with it a similar but insoluble compound, containing basic sulphate of alumina; the burning expels the water from the hydrate of alumina, and thus renders it chemically inactive; the excess of alumina is thus separated from the compound, which then yields an alum soluble in water. On evaporation (until the specific gravity is 1.114 at 45°=113° F.), the ley still holds a fine ferruginous* rose-red powder in suspension, which perceptibly colors the crystals, but is left when these are re-dissolved. The crystals contain potash, but no ammonia, and are highly prized in commerce, under the name of *Roman* alum.

Originally, all the alum consumed in Europe was produced from alum-stone, at Rocca (the modern Edessa), in Syria (hence the name

* According to some, this red powder is not ferruginous.

Rocc-alum—whence the corruption *Alumen rupeum* and *Alun de Roche*), and was brought from the Levant to the European market. In the year 1460 or 1465, the art of preparing alum was introduced at Tolfa by Johann de Castro, who first discovered the alum-stone in that locality. The art spread from thence in various directions, and in the 17th century the preparation of alum was commenced in Germany and England, although upon very different principles.

Production from Alum Ore.—In these latter countries Nature is far less propitious to the manufacture of alum, the mineral products yielding little more than alumina and sulphur towards the production of the salt. The chemical process which has been brought about by natural agency in the former countries with the aid of volcanic heat, has here to be effected by artificial means, and the alkali must also be supplied from other sources. The production of alum from alum-shale and alum-earth (the alum ores) is naturally arranged under three distinct operations: the production of sulphate of alumina; the addition of sulphate of the alkali to the concentrated cold solution of the former, in which operation difficultly soluble alum precipitates, in the form of powder, and is thus separated from the foreign salts; and, lastly, the purification of the flour by re-crystalization.

Alum-shale is a kind of clay-slate impregnated with sulphuret of iron and bituminous matters—a member of the younger transition series of rocks therefore—which is allied to real clay-slate, by its firmness, appearance, its slaty structure and its great extent. It is found on the Scandinavian peninsula, in Bohemia, in the Hartz, in Upper Bavaria, in Voigtland, in the mountainous districts of the Lower Rhine, in England (near Whitby), in Scotland, at Hurlet and Campsie near Glasgow, and in the Uralian Mountains, &c.

The following analyses show the composition of the rocks:

ALUM-SHALE FROM SIEHDA, BY LAMPADIUS.

Sulphate of alumina	2.68
Potash alum	0.47
Sulphate of iron	0.95
Sulphate of lime	1.70
Silica	10.32
Alumina	9.21
Magnesia	traces.
Oxide of iron	2.30
Oxide of manganese	0.31
Sulphur	7.13
Water	33.90
Carbon, &c.	31.03
	100.00

ALUM-SHALES, BY G. KERSTEN.

	Hermannsschachte.	Glückaufgang.	Blücherschachte.
Carbonaceous matters	41.10	27.92	34.20
Silica	44.02	51.32	50.21
Peroxide of iron	6.23	8.40	0.42
Alumina	5.60	7.62	5.21
Magnesia	0.32	0.26	0.53
Oxide of manganese	0.12	traces.	traces.
Sulphur	1.25	2.89	1.72
Sulphate of lime	traces.	traces.	traces.
	98.64	98.41	98.39

ALUM-SHALE, BY ERDMANN.

	Garnsdorff.		Wezelstein.	
Soluble in acid:				
Sulphuret of iron	7.533		10.166	
Silica	0.060		0.100	
Peroxide of iron	0.966		2.466	
Alumina	1.833		3.166	
Lime	0.400		1.000	
Magnesia	trace.		1.022	
		10.792		17.920
Insoluble in acid:				
Silica	50.066		52.200	
Alumina	8.900		17.900	
Peroxide of iron	1.300		3.366	
Magnesia	1.000		1.133	
Lime	trace.		trace.	
Coal	22.833		0.803	
		84.099		75.402
Water		2.208		5.080
		97.099		98.402

The following is the composition of several shales, which are sometimes employed in making alum:

1. Locality unknown; by D'Aubuisson.
2. Dunmeniss, in Devonshire; by Stokes.
3. Gaggenau, in Baden: by Holtzmann.
4. Niederselters, in Nassau; by Wimpf.
5. Goslar, in the Hartz; by Frick.
6. Brenndorff, near Coblentz; by Frick.
7. Lehsten, Thüringerwald; by Frick.
8. Prague; by Pleischl.

	1	2.	3.	4.	5.	6.	7.	8.
Silica	48.6	59.4	64.34	79.17	60.03	62.83	64.57	67.50
Alumina	23.5	17.4	23.90	10.42	14.91	17.11	17.30	15.89
Peroxide of iron	11.3	11.6	9.70	6.27	8.94	8.23	7.46	5.85
Oxide of manganese	0.5	—	—	—	—	—	—	0.08
Lime	—	2.1	—	—	2.08	0.83	1.16	2.24
Magnesia	1.6	2.2	—	—	4.22	1.90	2.60	3.67
Potash	4.7	—	—	—	3.87	4.17	1.99	1.23
Soda	—	—	—	—	—	—	—	2.11
Strontia	—	—	—	—	—	—	—	0.30
Oxide of copper	—	—	—	—	0.28	0.27	0.30	—
Fluoride of calcium	—	—	—	—	—	—	—	1.13
Phosphoric acid	—	—	—	—	—	—	—	
Sulphur	0.1	—	—	—	—	—	—	—
Carbon	0.3	—	—	—	—	—	—	—
Carbonic acid	—	—	—	—	5.67	4·66	4.62	—
Water	7.6	6.4	2.22	2.78				
	98.2	99.1	100 16	98.64	100.00	100.00	100.00	100.00

The following is the composition of some shales from Whitby, in Yorkshire; and Campsie, near Glasgow.

	WHITBY. Top Rock.	WHITBY. Bottom Rock.		CAMPSIE. Top Rock.	CAMPSIE. Top Rock.		CAMPSIE. Bottom Rock.
Sulphuret of iron	4.20	8.50	Sulphur	22.36	23.44	Pyrites.	9.63
			Iron	18.16	15.04		
Silica	52.25	51.16		15.40	15.40		0.47
Protox. of iron	8.49	6.11					2.18
Alumina	18.75	18.30		11.35	11.64		18.91
Lime	1.25	2.15		1.40	2.22		0.40
Magnesia	0.91	0.90		0.50	32		2.17
Oxide mangan.	traces	traces		0.15			0.55
Sulphuric acid	1.37	2.50					0.05
Potash	0.13	traces		0.90			1.26
Soda	0.20	traces					0.21
Chlorine	traces	traces					
Coal	4.97	8.29	Carbon & Loss.	29.78	Carb. 28.80		
							8.51
						aq.	8.54
Water	2.80	2.00			Loss. 3 13		0.59
	95.40 Rich.	99.91	Richardson.	100.00	99.99		100.00

It will be observed, that in the Campsie alum ores, the top ore contains a large excess of pyrites, yielding of course more sulphuric acid than the alumina can take up, while the bottom ore contains a considerable excess of alumina; it is, therefore, the object of the alum makers so to mix these ores that the different ingredients may be made available as far as possible

The following is the composition of the residue from the above Campsie ores after calcination and washing out the alum.

Silica	38.40
Alumina	12.70
Peroxide of iron	20.80
Oxide manganese	traces
Lime	2.07
Magnesia	2.00
Potash	1.00
Sulphuric acid	10.76
Water	12.27

Alum-earth belongs to the more recent deposits, occurring below the first strata of the tertiary coal formation, which are of a later period than the chalk. It is a massive but soft pulverizable mass, which is stratified, but not slaty, and of a dark brown color: it occupies basins of variable dimensions, according to the position of the neighboring rocks. Very large deposits of this formation occur in the valley of the Oder, and are worked at Freienwalde, Gleissen and Muskau. It is no uncommon phenomenon in the coal formations for the clay and coal strata to permeate each other in those localities where they come into contact. These deposits, which frequently cover the coal formation, and at other parts form alternate layers with the coal, play the part of alum ores, and may be worked for the production of alum, when they contain a sufficient quantity of sulphuret of iron, which is frequently the case. To this class belong the Scotch ores. In Upper Silesia it is even found profitable to make the refuse coal or brees, which cannot well be used as fuel, subservient to the production of alum; these coals leave an aluminous ash, and those which are rich in iron pyrites are only distinguished from a real alum ore by the large excess of combustible matter which they contain, and which in this case cannot be turned to account.

The mineral, which is quite as indispensable to the production of alum as alumina itself, is iron pyrites or the bisulphuret of iron (FeS_2). This compound is formed by the decomposition of protosulphate of iron (FeO,SO_3) held in solution in water by the fossil coal. Green vitriol, or protosulphate of iron, is deprived of oxygen by any organic substance which is retained for a length of time in contact with it, and becomes reduced to sulphuret of iron. The sulphuret is disseminated through the alum ores, partly in the well-known brilliant yellow crystals or crystalline deposits, but chiefly in a very fine state of division, as a dull black powder, somewhat resembling the mass obtained by precipitating a salt of iron by sulphuret of ammonium. Hence, inasmuch as it was not perceptible to the eye, its presence has not only been overlooked in the following analyses, but actually denied.

	ALUM-EARTH	
	from Freienwalde. Klaproth.	from Pützberg. Bergemann.
Alumina	16.00	10.80
Silica	40.00	45.30
Magnesia	0.25	—
Sulphur	2.85	3.94
Carbon	19.65	5.95
Protoxide of iron	6.40	5.50
" manganese	—	0.60
Protosulphate of iron	1.80	5.73
Sulphate of alumina	—	1.20
" lime	1.50	1.71
" potash	1.50	1.75
Chloride of potassium	0.50	0.35
Sulphuric acid	—	0.47
Water	10.75	16.50

The sulphur is therefore in combination with the iron as sulphuret of iron, and not, as was formerly supposed, as sulphur or as sulphuret of carbon. Although the constituents of alum-earth are nearly the same in specimens taken from other localities, the proportions are nevertheless variable, as might have been expected from the mode in which the deposits are formed; so great, indeed, is the difference in this respect, that the examples given above can hardly be viewed, as a fair average of these compounds. The pyrites and the alum ores owe the property of being rapidly decomposed, under the influence of atmospheric air, to the fine state of division of the bisulphuret and, probably also, to the occasional presence of the protosulphuret of iron.* Massive crystalline pyrites is very slowly decomposed under the same circumstances. The decomposition is occasioned by 7 equivs. of oxygen being taken up by the pyrites (FeS_2), which convert it into protosulphate of iron and sulphuric acid, FeO,SO_3 and SO_3. In those parts of the heap where the temperature is excessively high, the pyrites is converted, as by roasting, into sulphur and protosulphuret, or $\frac{8}{7}$ sulphuret of iron, which immediately burn, the former to form protosulphate of iron, and the latter sulphurous acid, which is absorbed by the alumina. The sulphite of alumina thus formed is easily converted by absorption of atmospheric oxygen into sulphate of alumina.† The sulphurets of iron are, therefore, only instrumental to the production of alum by affording the necessary amount of sulphuric acid to combine with the alumina; besides the acid yielded by the second portion of sulphur in the bisulphuret, another portion is combined with alumina by the decomposition of the green vitriol, the protoxide of iron in which is speedily converted into peroxide by the oxygen of the air, and is precipitated in the form of a basic salt. According to Scheerer, this basic salt, as it occurs in the decomposed alum ores, contains in 100 parts, 56.5 parts iron to 6 sulphuric acid, whereas in green vitriol, there are 63 parts of sulphuric acid to the same quantity of iron; the difference 63—6=57 parts of sulphuric acid has consequently taken part in the production of alum; vide copperas section below. The presence of potash, which is never altogether wanting in the alum ores, gives rise in a similar manner to the liberation of sulphuric acid by the production of basic sulphate of potash and iron; persulphate of iron is also decomposed by hydrate of alumina, and sulphate of alumina dissolves, but the greater portion remains insoluble with the basic sulphate of iron.

* That this is an exceptional case, is proved by the greater number of alum ores yielding no sulphuretted hydrogen with dilute mineral acids.

† Or what is more likely, by reducing the sulphate of peroxide of iron to the state of sulphate of protoxide. The alum ore, when fresh taken from the ridges (the name given to the calcined heaps) and covered with water, which is removed after a short interval, will be found to have yielded little sulphate of alumina to the solution, but a great deal of sulphate of peroxide of iron; while after being allowed to remain for some time over the ore, the solution will be found to contain both much sulphate of alumina and sulphate of protoxide of iron. The alum makers know that the first washes are not those which yield the most alum, unless the ore has been allowed to remain in the steeps for a considerable time; they also know that more alum is obtained by adding a portion of mothers which are very rich in persulphate of iron to the wash-water than can be obtained by pure water alone.

The presence of lime in the ores is most prejudicial, for this base deprives both the sulphates of alumina and iron of their sulphuric acid, and entirely puts a stop to the production of alum. Ores containing any considerable quantity of lime, cannot, consequently, be used in this manufacture. Gypsum, however, is always found in the crude leys. Magnesia is no less deleterious to the formation of alum, but the sulphate of magnesia thus produced, is not a totally valueless salt.* Fresh alum ores contain no soluble salts of alumina or iron; it is only where air has had access to them, either in the pit or at the surface, that efflorescence in the form of fine needles, *feather alum*, is observed, and this consists, partly of real alum, partly sulphate of alumina, or also of combinations of the latter salt with protoxide of iron, sulphate of magnesia, &c.

An alumina sulphate of iron also occurred abundantly some years ago, in the Hurlet and Campsie wrought-out coal beds, which had the following composition.

	Berthier.	Phillips.	R. D. Thomson.	R. D. Thomson.
Sulphuric acid	34.4	30.9	35.600	28.635
Protoxide of iron	12.0	20.7	13.560	19.935
Alumina	8.8	5.2	7.127	2.850
Magnesia	0.8	—	—	—
Water	44.0	43.2	43.713	48.580
	100	100	100	100

The composition of this "Feather alum, or hair salt," as it is termed, in different localities, is shown by the following analyses:†

COMPOSITION OF NATURAL SULPHATE OF ALUMINA (ALUMINITE).

	Halle, Germany.									Morl.	New-haven	Epernay.
Alumina	39.50	36.0	37.7	38.81	35.961	36.17	32.50	31.0	30.26	30.98	29.87	39.70
Sulph. acid	11.45	17.0	12.22	12.44	14.039	14.54	19.25	21.5	23.37	23.69	23.37	20.06
Peroxide of iron	—	—	—	—	—	—						
Lime	—	—	—	—	—	—	1.25	2.0	—	—	—	—
Silica	—	—	—	—	—	—						
Carbonate of lime	—	—	1.00	1.68	—	—	—	—	—	—	—	0.30
Water	48.80	47.2	49.18	47.07	50.000	49.03	47.00	45.0	46.37	45.33	46.76	39.94
	99.75	100.2	100.11	100.00	100.000	99.74	100.00	99.5	100.00	100.00	100.00	100.00
	Marchand.		Backs	Wolff.	Martens.	Schmid.	Simon	Buchhoby.	Stromeyer.			Lassaigne.

* In the English alum works, the sulphate of magnesia is a most important object in the manufacture.

† The term "*hair salt*," sometimes applied to these natural effloresced substances, belongs more properly to the sulphate of magnesia which sometimes accompanies them.

COMPOSITION OF NATURAL SULPHATE OF ALUMINA (FEATHER ALUM).

	Saldana. (Columbia.)	Pasto. (Columbia.)	Pyromeni, in Island Milo.	Coquimbo, Chile.	Bogota.	Kolosorak, Bohemia.	Friesdorff, near Bonn.	Potschappel, near Dresden.	Freienwalde.	Ararat.	Huelgoëth, Bretagne.	Andes.	Campsie, Glasgow.	Adelaide, New South Wales.
Sulphuric acid	36.400	35.68	40.31	36.97	29.0	35.82	37.380	35.710	35.637	58.58	12.9	35.872	40.425	35.63
Alumina	16.000	14.98	14.98	14.63	15.0	15.57	14.867	12.778	11.227	38.75	41.5	14.645	10.482	17.09
Peroxide of iron	0.004	—	—	2.58	1.2	—	—	—	—	—	—	0.500	8.530	0.04 copper, ox. of
Protoxide of iron	—	—	—	—	—	—	2.463	0.667	.718	SO_3, FeO 2.78	—	—	—	—
Protox. manganese	—	—	—	—	—	—	—	1.018	0.307	—	—	—	—	—
Potash	—	—	0.26	—	—	—	0.215	0.324	0.430	—	—	—	1.172	—
Soda	—	—	1.13	—	—	—	—	—	—	—	—	2.262	—	—
Lime	0.002	—	—	—	—	—	0.149	0.640	0.449	—	—	—	—	—
Magnesia	0.004	—	0.85	0.14	—	—	—	0.273	1.912	—	—	—	—	—
Muriatic acid	—	—	0.40	—	—	—	—	—	—	—	—	—	—	—
Silica	—	—	1.13	1.37	3.0	—	—	—	0.430	—	3.5	0.100	—	0.50
Water	46.600	49.34	40.94	44.64	51.8	48.61	45.164	47.022	48.847	—	42.1	46.375	36.295	46.70
	99.010	100.00	100.00	100.33	100.0	100.00	100.238	98.432	100.000	100.11	100.0	99.754	96.904	99.96
	Boussingault.		Hartwell.	H.Rose	Mill.	H. Rose.				Göbel.	Berthier.	T. Thomson.		Herapath.

* This specimen was found in thin bands traversing the waste or washed shale which had been once extracted, and yielded a further product of alum on being again burnt.

Roasting or *Ustulation.*—Many kinds of alum ore are so rapidly acted upon by the air, that the heat which ensues is sufficiently intense to fire spontaneously the carbonaceous parts; others, on the contrary, like the alum-shales, are so dense that they must be disintegrated by roasting, in order to open a free passage of air into the interior of their mass. This operation is conducted in the open air by interstratifying the ores with fuel, such as brushwood, coal or peat, and igniting the heap, either one layer at a time, as it is added to the heap or "ridge," or the whole heap at once. The fire is regulated in the same manner as in the charcoal mounds. An increased draught is brought about by making air-holes, and the draught is impeded by heaping exhausted or disintegrated ore upon those parts where this is required. Many alum ores, however, as for instance the Campsie ores, contain so much coally matter, that they cannot be calcined without a large proportion, in most cases one-half of exhausted ore, and the heaps require only a small quantity of coal to commence the combustion.

The pyramidal form of the ridge or heap protects it pretty well from the penetration of rain, but it is found expedient to collect what flows from the bottom of the ridges in tanks adapted for the purpose.

The first action of the heat in the roasting process is to expel the half of the sulphur from the pyrites. This portion is partly burnt into sulphurous acid, and partly sublimed on the outer colder parts of the heap, whilst the protosulphuret which remains, or when the heat has not been great, the $\frac{8}{7}$ths sulphuret, is converted at a later period into green vitriol, after the combustible part of the heap is consumed. The mass of the shale is loosened very much at the same time, and converted into a red ash, with a considerable diminution of volume; the shale of Lüttich (Liege), for instance, loses 28 per cent. in weight.* The ores which undergo spontaneous decomposition, are treated in precisely the same manner, with the omission of the fuel to the heap, and care is taken to supply a sufficiency of moisture, without which no decomposition could occur. A clay bottom is well adapted for the erection of a heap, that none of the salts may be carried by the moisture into the soil; the heap is also sometimes constructed under a shed. As a general rule, it is found that the produce is better, the slower and more uniform the heat is regulated. It is sometimes necessary in foul weather to cover the heap with coal refuse, or to shovel fresh ore upon those parts that have become too hot. When the heat rises to a certain pitch, and the mass attains a red heat, the sulphate of alumina is decomposed, its acid is expelled, the loss of which is, however, in some measure compensated by the simultaneous loss of acid by the green vitriol; the acid from both sources is, however, partly retained by the covering of exhausted ore, and it is hence particularly advantageous to use that substance for this purpose. A very

* At Salzweiler, near Dultweiler, in Rhenish Prussia, this roasting is effected spontaneously in the pit, by the aid of a stratum of brown coal below it, which has continued in a state of slow and restricted combustion ever since the year 1660, when it was accidentally fired.

great excess of heat might soften the sulphurets and cause them to cake together, instead of becoming porous. It will be easily conceived, that the decomposition of such great masses of ore as are comprised in a heap of from one to several hundred feet in length, impeded as it is, cannot proceed very rapidly; ore that has not been roasted, requires ten or twelve months [more commonly 18 to 24 months], and roasted ore, from six to eight weeks, in order to be thoroughly decomposed. The state of the heap is judged of by extracting portions of the ore, or by the taste and general appearance of the decomposed mass.

Lixiviation of the Roasted Ores.—The period has now arrived for extracting the sulphate of alumina, and the other soluble salts. Precisely the same precautions and arrangements are here requisite, as have been already described under the "Lixiviation of Saltpetre Earth," (vol. i. p. 328), and the saving of time and fuel is, in the case of alum, a matter of still greater importance, on account of the great competition to which the manufacture is exposed.

The roasted ore is spread out in large wooden tanks lined with lead, or in some instances in walled cisterns, over a false bottom upon straw, and is covered with water. At Valmunster, in the department of the Moselle, these tanks are constructed of burnt stones and clay, and each has a capacity of 1728 C. F. (1380 C. F. Rhenish). At the bottom, beams are arranged at certain distances from each other, upon which a layer of straw and brushwood is laid, and upon this the false bottom of boards is placed. This whole arrangement forms the filtering apparatus, from which the ley flows through apertures at the sides. Each cistern requires 1280 C. F. of water for the lixiviation. Ley is first poured upon the ore of 20° B. (=sp. gr. 1.157); when this has run off, it answers to 24° or 25° B., and is fit for boiling; a weaker ley of 15° B. (=sp. gr. 1.113), and subsequently others of 10° B. (=sp. gr. 1.072), and the weakest of 5° B. (=sp. gr. 1.034) then follow; and lastly, the whole is washed out with pure water. All the leys that fall short of 24° or 25° B., are poured upon more or less exhausted ores, according to their strength. By arranging these cisterns upon terraces, the one above the other, the ley can easily be drawn from the upper into the lower cisterns, until it has acquired the proper strength. The solution is then called crude liquor, and is preserved in large walled tanks, ready for further operations.

According to Mr. Scanlan, quoted by Dr. Ure, eight different liquors are met with in the alum works on the Yorkshire coast.

1st. "*Raw liquor.*"—The calcined alum-shale is steeped in water till the liquor has acquired a specific gravity of 9 or 10 pennyweights,* according to the language of the alum maker.

* The alum makers' specific gravity bottle holds 80 pennyweights of water, and by 10 pennyweights he means 10 more than water, or 90. The numbers on Twaddle's hydrometer divided by 2.5, give alum makers' pennyweights.

The alum manufacturer tests his samples of potash comparatively, by dissolving equal weights of the different samples in equal measures of alum-liquor at 20 pennyweights, heated up to the boiling point and weighing the quantity of alum crystals produced on cooling.

2d. "*Clarified liquor.*"—The raw liquor is brought to the boiling point in leaden pans, and suffered to stand in a cistern till it has become clear; it is then called clarified liquor. Its gravity is raised to 10 or 11 pennyweights.

3d. "*Concentrated liquor.*"—Clarified liquor is boiled down to about 20 pennyweights. This is kept merely as a test of the comparative value of the potash salts used by the alum maker.

4th. "*Alum mother-liquor.*"—The alum pans are fed with clarified liquor, which is boiled down to about 25 or 30 pennyweights, when a proper quantity of potash salt in solution is mixed with it, and the whole run into coolers to crystallize. The liquor pumped from these rough crystals is called "*alum mothers.*"

5th. "*Salt-mothers.*"—The alum-mothers are boiled down to a crystallizing point, and afford a crop of "*rough Epsom,*" which is a sulphate of magnesia and protoxide of iron.

6th and 7th. "*Alum washings.*"—The rough crystals of alum (No. 4) are washed twice with water, the first washing being about 4 pennyweights, the second about $2\frac{1}{2}$, the difference in gravity being due to mother-liquor clinging to the crystals.

8th. "*Tun-liquor.*"—The washed crystals are now dissolved in boiling water and run into the roaching-tuns (wooden vessels lined with lead) to crystallize. The mother-liquor of the "*roach-alum*" is called "*tun-liquor;*" it is of course not quite so pure as a solution of roach-alum in water.

With reference to the exhausted residues, two cases may occur: They have either been rendered perfectly porous by the roasting and decomposition, in which case they will have been completely exhausted, and may be thrown away unless they can be used for covering fresh heaps; or they still contain portions of undecomposed ore, and may then be subjected to a second exposure (as at Buchsweiler, in Elsace), either by themselves or mixed with fresh ore. The process in many other alum works, where the ores do not require roasting, is essentially the same as that described above. The lixiviation, however, is then carried on with the heaps themselves and during the process of decomposition; they are erected for this purpose upon so-called "*Bühnen,*" which consist of flat wooden boxes, or upon a foundation composed of brick-work or clay, which is impervious to the liquor, and whence the water which is pumped from time to time upon the heap collects, and is conducted away to the crude liquor cisterns. The soluble salts are thus collected at certain periods, as they are produced during decomposition. The strength of the crude liquor in the cisterns must be regulated by the respective prices of labor and fuel, weak liquor requiring more of the latter, and strong liquor more labor; it is never, however, advisable to concentrate the liquor to that degree at which it would be saturated with the crystallizable salts like green vitriol and sulphate of magnesia, as these would crystallize with the slightest amount of evaporation or rise of temperature, before it is desirable that they should do so. In general, the density indicated by 20° B (= sp. gr. 1.157) is not exceeded.

Simon found the crude liquor from Gleissen, in Neumark, to contain the following ingredients:

Sulphate of alumina - - -	11.085	=29.678 per cent.
Protosulphate of iron - - -	9.773	
Sulphate of soda - - - -	2.035	
Sulphate of magnesia - -	1.754	
Sulphate of manganese - -	0.174	
Sulphate of potash - - -	0.095	
Sulphate of lime - - - -	0.120	
Perchloride of iron - - - -	1.872	
Chloride of magnesium - -	0.334	
Chloride of aluminium - -	0.419	
Free sulphuric acid - - -	0.563	
Free hydrochloric acid - -	1.454	
Water - - - - - - -		70.322
		100.000

A certain quantity of ready formed alum always accompanies these constituents, sometimes potash, sometimes ammonia-alum, when a red heat has not been employed in the manufacture, which decomposes the latter, leaving only alumina unvolatilized. To the production of the former, the potash naturally contained in the ores assists, and still more that which exists in the ash of the wood employed as fuel; the ammonia is attributable to the nitrogen contained in the coal. During the time that the crude ley is clarifying in the large vats, a chemical decomposition ensues, by the action of the air upon protosulphate of iron, and this is not prevented by the state of solution of the salt:

$$\begin{array}{lll}
10 \text{ equivs. } FeO,SO_3 & = 10\,Fe + 10\,O + 10\,SO_3 & \text{absorb from the air} \\
5 \text{ equivs. oxygen} & = \quad\quad 5\,O & \\
\hline
 & 10\,Fe + 15\,O + 10\,SO_3 & \text{and a basic salt} \\
= 2\ Fe_2\,O_3,\ SO_3 & = 4\,Fe + 6\,O + SO_3 & \text{is produced and}
\end{array}$$

precipitated, whilst:

3 equivs. of $Fe_2O_3,3SO_3 = 6\,Fe + 9\,O + 9\,SO_3$, or an acid persalt remains in solution.

In the foregoing analysis, this acid salt has probably been overlooked, or its constituents have been appropriated in some other manner; in the high state of dilution of the crude ley, however, nearly the whole of the oxide of iron is precipitated, and a very small portion remains in solution. This is turned to account, by mixing the crude liquor with the mud which is obtained in a subsequent operation. This mud is a kind of basic alum, *i. e.* an insoluble salt, which is deficient in a certain quantity of sulphuric acid to render it neutral alum. The deficiency is then supplied at the expense of the acid persulphate of iron, or of the free sulphuric acid. The basic persalt of iron is called, in German, "*Vitriolschmand*," and is collected from time to time from the bottom of the cisterns and heated to redness; it

then parts with its acid and the peroxide remains, which is used as a red pigment.

Boiling the crude ley.—The further treatment of the ley depends upon the quantity of green vitriol which it contains, and in most cases there is quite as much, or more of this than of alum. The ley is then used for the production of both salts, and alum and vitriol works are generally carried on conjointly; but the process of separating the two salts by crystallization varies much in different manufactories.

When the crude ley is very much charged with the salt, it is evaporated in pans, into which old iron is thrown. The persalt formed by the action of the air is thus partly precipitated as a basic salt,* one portion of the acid entering into combination with a fresh portion of iron with the evolution of hydrogen gas, and is again partly reduced to a salt of the protoxide, which prevents the decomposition of the green vitriol, and crystallizes in large crystals from the solution. In order to afford more points of attachment for the crystals, and facilitate their removal, the workmen are in the habit of hanging peeled sticks and branches in the solution. The mother-ley of course contains the whole of the sulphate of alumina, and is boiled for alum in the manner to be subsequently described.

In other places (as at Reschwitz, near Saalfield, at Schwemmsal) the greater portion of the water is removed by graduation, as in the salt works (vol. i. p. 251), when, in consequence of the increased action of the air, a considerable portion of the green vitriol is decomposed, and much basic sulphate of iron, mixed with gypsum, is left as an incrustation upon the thorns. The graduated ley then yields green vitriol on evaporation, and a mother-liquor containing the alum.

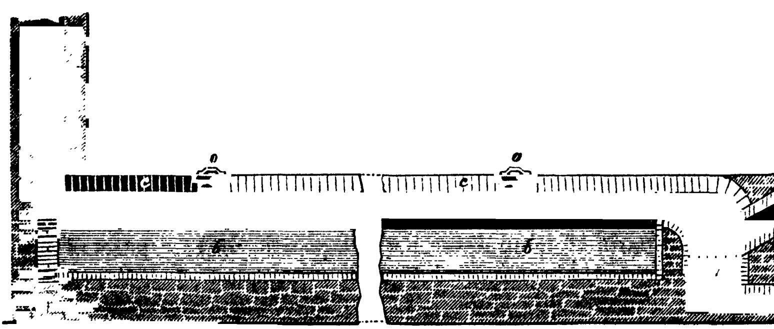
Another process consists in separating the copperas, not by cooling the saturated solution, but by simple evaporation or abstraction of water, as in the soccage of common salt, (for instance, at Buschweiler). When evaporation has been carried on for some time, and the loss of water and the strength of the ley have reached a certain degree, a point of saturation is attained (when the specific gravity is equal 1.35 to 1.37, or 38° to 40° B.) at which the remaining water is just sufficient to retain the copperas in solution. The evaporation of every additional quantity of water then causes the precipitation of a portion of copperas, and a sediment, consisting of very small anhydrous or slightly hydrated crystals, is rapidly deposited. In the meantime, the evaporated water is constantly replaced by fresh liquor. It is obvious that upon this plan, in which the liquor is always saturated, the quantity of dissolved copperas cannot increase in the pan; whilst the amount of the other soluble salts (sulphate of alumina) must increase until the liquid is saturated with them. In fact, the strength of the liquor increases simultaneously with the deposition of the copperas, and that point must be watched, when the strength of the

* This precipitate falls without the addition of metallic iron, as dilute solutions of persulphate of iron ($Fe_2O_3,3SO_3$) are decomposed by heat alone, and a basic salt ($3Fe_2O_3,SO_3$) is precipitated.

liquor is not further augmented, (when the hydrometer sinks to the same point,) that the other salts with which it will then be saturated, may not precipitate with the copperas. On the one hand, therefore, we obtain, the precipitated copperas, which is purified by recrystallization, and its water of crystallization raised to 7 equivs.; and on the other, a mother-liquor saturated with sulphate of alumina for the production of alum.

When, on the contrary, the copperas is not in excess, the process is reversed, and begins with the production of alum from the crude liquor. This is then pumped at once from the crude liquor cisterns, in which it has been clarified into the evaporating-pans. If these are composed of tinned iron, they become attacked by the sulphate of alumina, and the ley, with the evolution of hydrogen and basic sulphate of alumina, is precipitated when the action, which is similar to that of an acid, is not prevented by the addition of the basic mud before mentioned. Notwithstanding this, the sediment frequently gets burnt on to the bottom, and causes difficulty and damage, particularly when cast-iron or leaden pans are employed, which are not otherwise affected, but the former of which is brittle and the latter too easily melted by the heat. To prevent this burning, metal evaporating-pans

Fig. 132.



are now almost universally discarded, and the flame is carried over the surface of the liquid instead of below the pan, as in Fig. 132, which represents one of the most commodious and generally-used evaporating-furnaces. The liquor is placed in the basin *b b*, the walls of which are constructed of bricks, placed upright, and well cemented with a mortar composed of lime and lixiviated alum-shale-waste. The grate *r* is purposely placed somewhat low, that very little ash may be carried mechanically by the flame into the pan; the flame passes below the flat arch *c* to the chimney. The apertures *o o* are adapted for observing the interior at different parts. The reverberatory-furnace is either very long, as shown in Fig. 132, in order to obtain the full heat of the fire, or is connected with a pan which can be warmed by the same fire. Any loss of heat is thus precluded, and the draught of the furnace ensures, in the simplest manner, a constant current of air over the liquid, which is favorable

to evaporation. Fresh liquor, or the mother-liquor from a previous operation, is added as the water evaporates, until the contents of the pan attain 42° B. (spec. grav.=1.40) which is the most fit state of concentration for producing the flour or meal in the next operation. In the meantime, a copious sediment is deposited from the ley, consisting of a large proportion of basic sulphate of iron, (produced by the continuous decomposition of the copperas and neutral persulphate of iron,) of gypsum and other salts, which renders it necessary to clear the liquor in the cooling-vats. Whatever the composition of the liquor may be, it must never be so far evaporated as to deposit salt by cooling in the vessels appropriated to the production of the flour. Everything must remain in solution after cooling, and the liquor must be perfectly clear.

Preparation of the Powder.—The flour or powder-cisterns are those vessels in which the sulphate of alumina is combined with potash or ammonia (the *flux* or *precipitating substance*) in such a manner as to effect the first purification of the alum. The alum is only very slightly soluble in *the cold* mixture of the liquor with the solution of the precipitating substance. The greater portion of the alum is consequently precipitated in the form of very small crystals, or *flour*, by reason of the agitating motion given to these cisterns or boxes, which enclose no mother-liquor, and can easily be freed from the portion attached to them by means of water.

Potash and ammonia alum are in this respect very much alike; 9.25 parts of the former dissolve in 100 parts of water at 10° C. (F. 50°), and 9.16 parts of the latter (in the form of crystals); this is not the case with soda-alum, of which 100 parts of water at 10° C. (F. 50°) takes up 46 parts. Sulphate of soda is consequently not applicable to the production of cheap and pure alum. According to theory, 50.9 parts of neutral sulphate of potash, or 47.8 parts of sulphate of ammonia are required for the conversion of 100 parts of sulphate of alumina into alum. The precipitating substance cannot be employed in the dry state, as the point of saturation would not then be distinctly known, and the flour is easily contaminated by an excess, which, when sulphate of potash has been used, is difficultly removed on account of its sparing solubility. On the other hand, perfectly saturated liquor is only used, that too much water may not be introduced into the flour cisterns, and the largest produce of meal may be obtained.

When it is assumed for the sake of simplicity that the liquor to be used, which may have a temperature of 10° C. (50° F.), is saturated with green vitriol and alum, it will then contain:

for every 100 parts of water,
33.2 " of anhydrous protosulphate of iron, and
33.5 " of anhydrous sulphate of alumina;

these ingredients require 17.1 parts of neutral sulphate of potash, which are held in solution by 66 parts of boiling water. On mixing this solution with the ley, 96 parts of crystallized alum will be pro-

duced, together with $100+66=166$ parts of water. Of the 96 parts of alum, only 16 parts can remain in solution when the liquid has cooled to the primary temperature of 10° C. (50° F.); and consequently $96-16=80$ parts of alum will be precipitated in the form of powder; and this quantity will be diminished in practice in proportion to the lesser state of saturation of the solution. The use of chloride of potassium is preferable to that of sulphate of potash, as less of it is required, in the proportion of 100 : 117 for the same quantity of alum, and the chloride being soluble in 2 parts of boiling, or 3 parts of cold water, the flour can be precipitated in the cold.

In the instance given above, the 33.5 parts of sulphate of alumina would require 14.5 parts of chloride of potassium for precipitation, and these would be soluble in 26.2 parts of boiling water, and produce 96.5 parts of alum. After the mixture had been made under the same circumstances, 12 parts would remain in solution, and 84.5 parts would be precipitated in the form of flour. The same quantity of chloride of potassium requires, however, 46 parts of water of 10° C. to dissolve it, which, when added to the liquor, will precipitate 84 parts of flour, whilst 13.8 parts of alum will remain in solution. The difference is, therefore, not great in the two cases. A similar advantage is obtained by the use of sulphate of ammonia, which also dissolves in 2 parts of boiling water, but this yields less alum in the proportion of 100 : 95.6; the equivalent of ammonia-alum being so much less than the equivalent of potash-alum. In fact the 33.5 parts of sulphate of alumina, in the above instance, require 15.8 parts of sulphate of ammonia, in order to be completely converted into 87.7 parts of alum. After precipitation, however, 10.6 parts of alum remain in solution, and 77 parts are precipitated as flour. The disadvantage occasioned by the lesser equivalent of ammonia-alum is thus counterbalanced by the greater solubility of the ammoniacal salt as a precipitating substance.

Sulphate of potash for the alum manufacture is obtained as a secondary product in the nitric acid manufactories, from the burners of the vitriol chambers on the old plan of manufacture, and also in the process of purifying potashes, &c. It is generally all, or in part, in the form of bisulphate ($KaO,2SO_3$), and should in this case be converted by the addition of potashes into the neutral salt (KaO,SO_3). This is the only case in which potashes can be used, except when an excess of acid is present. If, on the other hand, no free acid is present, and potashes are employed, a portion of the sulphate of alumina will invariably be precipitated as basic sulphate of alumina and potash (basic alum), a salt which is always produced in lesser or greater quantity during evaporation; for instance, by the action of the iron, which can be re-dissolved by the addition of bisulphate of potash. It would be desirable always to combine the process of purifying potashes with the production of alum; so that not only the sulphate of potash, but also the chloride of potassium, might be turned to account. This latter salt, when added to the liquor, undergoes mutual decomposition with the sulphates of the metallic oxides and

the earths, while sulphate of potash and metallic or earthy chlorides are produced; the advantage derived in this case is considerable, for besides the small quantity of sulphate of magnesia, the whole of the proto and persulphates of iron can be converted into proto and perchlorides, both of which salts are deliquescent, and can be removed from the flour with much less difficulty than green vitriol. The use of chloride of potassium is of still greater importance when persulphate of iron is present in the liquor, for this salt, in combination with sulphate of potash, forms a difficultly soluble, but not insoluble, compound, the basic sulphate of iron and potash (basic iron-alum) which is precipitated in the form of a yellow powder, and contaminates the alum-flour. When all the other sulphates have become converted into chlorides, the sulphate of alumina would also be decomposed in its turn, and any further addition of chloride of potassium, by giving rise to the formation of chloride of aluminium, would prove a source of loss. For this reason, the nature of the ley must be investigated before every operation, with a view to determine the precise amount of chloride of potassium that is required to be added; for the amount of chloride of potassium that is necessary to precipitate the whole of the alumina as alum, will seldom or never meet with sufficient sulphate of iron in the ley to become converted into sulphate of potash. Circumstances, and the production or non-production of green vitriol from the mother-liquor must decide the quantity of chloride of potassium that should be employed. This salt is also supplied in quantity from the soap works (as soap-boilers' waste, vol. i. p. 416), the saltpetre refineries (vol. i. p. 342), and the glass-houses (as salts or sandiver, vol. ii. p. 39). Wood ashes should never be used, not even with the addition of sulphate of potash, on account of the lime which they contain. Varec (vol. i. p. 285), on the contrary, is frequently used in France, and kelp (vol. i. p. 285) in England. Wherever illuminating gas is obtained from coal, the cheap ammoniacal salts collected from the condensers and saturated with sulphuric acid (vol. i. p. 475), or converted into sulphate of ammonia by gypsum or green vitriol, may be employed with advantage; in like manner, the crude ammoniacal liquor obtained in the manufacture of sal-ammoniac by the dry distillation of animal refuse, may be applied to the same purpose.

In order that no loss of the precipitating substance may be sustained, it is necessary to determine the requisite quantity before the operation is commenced. With this object in view, a saturated boiling solution of the precipitating salt is added from a graduated burette, under constant agitation, to a measured quantity of the liquor as long as the flour which falls increases in quantity. The number of measures which have been employed indicate with sufficient accuracy the amount of solution required to precipitate a given volume of the liquor, and the tedious process of weighing is thus obviated. If the liquid, however, is allowed to cool during the operation, a portion of sulphate of potash (on account of its difficult solubility) may be precipitated with the flour, and give rise to an error; for this reason it is

advisable to use as the testing liquid the easily soluble sulphate of ammonia, of which 1 part is equivalent to 1.32 parts of sulphate of potash, or to 1.13 parts of chloride of potassium.

When the precipitating substance has been prepared and selected in accordance with these principles, the production of the flour is commenced by gradually adding the alkaline liquid to the liquor, which is kept in a state of continual agitation, until the flour has completely subsided. When this is finished, the workmen shovel the flour upon a slanting board at the side of the precipitating vat, that the mother liquor may run back. A portion of this mother-liquor, however, remains amongst the crystals, and is the cause of their brownish yellow color. The removal of this is the object of the next operation, or the *washing*. The same principles might be applied here as have already been mentioned under the refining of saltpetre (vol. i. p. 341): but it is generally considered sufficient to stir the meal in another vessel with a small quantity of cold water, which takes up the mother-liquor and a proportion of the crystals corresponding to the temperature, and this operation is repeated once or twice. The first two portions of wash-water consist of liquor of medium strength, and are added to the evaporating-pans, whilst the last portion is used instead of fresh water for the next washing.

Crystalization.—The washed meal is not sufficiently pure, nor is it in the proper form for sale; the consumers require the product to be in large crystals, that deception may not be practised by mixing other powders of a similar appearance and character with the alum. Both requisitions are met by a second crystalization. The flour is either added to boiling water in copper vessels, until the point of saturation is attained, or is more advantageously dissolved by the aid of steam. At Valmunster, for instance, this operation is performed in wooden troughs, lined with lead, and covered over with a lid. In the lid there are two apertures, the one for the reception of the steam pipe, 4 lines in diameter, and into the other a wide leaden funnel is inserted up to the margin, the sides of which are pierced with holes, 3 lines in diameter, three hundred of which are spread over a square foot. This funnel being kept filled with the alum powder, the steam, in endeavoring to escape through the apertures of the funnel, dissolves the alum. The saturated solution which flows through is thus retained at the temperature of the steam. In a trough of this kind, 4 feet high and 2 feet wide, 36 cwts. of alum can be dissolved in an hour. A residue of basic alum is generally left in the funnel, which is removed and employed as already stated above. The saturated solution (of 48° to 50° B = 1.485 to 1.515 sp. gr.) is now allowed to flow (by means of a leaden stop-cock) into the so-called *growing vessels* or *roaching-tuns*. This is the term given to the crystalizing casks, which are constructed of simple wooden staves without any lining of lead. They are about 5 feet high, and 3 feet in diameter at the top, gradually diminishing in the shape of a cone towards the bottom, but in such a manner that the staves remain straight, so that by removing the hoops they may be easily taken to pieces. The greater part of the alum (78 per cent. at Valmunster) separates, on cooling, in very large crystals,

sometimes weighing 1 lb. each, which form a connected crust all round the sides of the cask, with the points of the crystals to the interior, and which is twice or three times as thick at the bottom. The crystalization assumes indeed the form of a vessel composed of alum, which is sufficiently strong to support itself. When, therefore, the hoops are knocked off, the staves may be removed dry, and several holes are made with a pointed axe in the saline crust, that the mother-liquor may run out into a gutter in the stone floor, and be conducted to a separate cistern.* The mass of alum is lastly broken into large lumps, which are dried and packed for sale.

Fig. 133 represents one of these crystalizing casks from which a workman is removing the staves.

Fig. 133.

* When the roaching-casks are broken down, and the alum removed, a considerable quantity of white slime, mixed with small octahedral crystals of alum, is always found at the bottom. A quantity of this slime, washed until all the alum was removed, was found to be composed of:

Sulphuric acid	39.40
Alumina	31.80
Potash	10.03
Moisture	16.70
Insoluble	2.29
	100.22

The insoluble portion contained:

Silica	73.79
Alumina, with trace of iron	21.83
Lime	3.49
	99.11

The Mother-Liquor.—The mother-liquor is composed of a saturated solution of persulphate and protosulphate of iron, of chlorides of iron, sulphate of magnesia, and sulphates of the alkalies: besides these, it contains soda-alum, when soap-boilers' waste (chloride of potassium, containing chloride of sodium), or when the bisulphate of an alkali saturated with wood ashes, has been employed as the precipitant, also sulphuric acid and other compounds in small quantity. The nature of the ores determines whether the one or other salt is in largest quantity, and affords a clue to the subsequent application of the mother-liquors. To those which are acid and contain iron, old iron is added, which converts the peroxide into protoxide of iron, and green vitriol is obtained. Others which contain much chloride of iron are evaporated to dryness and heated to redness; the iron is then obtained as peroxide, which is used as a pigment. The mother-liquors are sometimes employed to saturate crude carbonate of ammonia (of the gas-works), and give rise to the production of sulphate of ammonia. Lastly, some of the ores contain so large a proportion of magnesia, that the mother-liquors can be used as a source of Epsom salts.

Produce.—The great variations in the character and richness of the ores, do not admit of even an approximative relation being established between the quantities employed and the amounts of alum produced in the different works. Thus, at Valmunster, from 17,300,000 lbs. of alum-shale, 400,000 cwts. of alum, or 2.3 per cent. are obtained, for the production of which, 100,000 lbs. of sulphate of potash are required, and 1,400,000 lbs. of coal are consumed. The slate of Lüttich (Liege) yield only 2 per cent. of alum, and that from other localities only 1 or ½ per cent.

The following is the mode of manufacturing alum, generally followed at Hurlet and Campsie, in the neighborhood of Glasgow. The calcined ore from the ridges is wheeled into large stone cisterns, called steeps, which are filled to about 18 inches above the false bottom, formed of loose planks resting on transverse beams. A wash from a previous steep is run upon this until it is completely covered, and allowed to rest for 8 hours; a plug is then removed from the bottom, and the liquor, which should have sp. gr. of 20° Twaddle, is run into the supply-cistern to settle; a second wash, of weaker liquor than the first, is then added, and allowed to stand as before, when it also is run off to the cistern. The operation is repeated if necessary, until the liquor falls below 12° Twaddle, at which strength it is not economical to evaporate, but the liquor is returned, as a first or second wash, to a fresh steep, according to its strength. The washing is continued with weak liquor, and finished with water. When the ore is considered exhausted, it is either wheeled to the waste heap or returned upon fresh ridges for the purpose of preventing too rapid combustion. The mixed liquors having been allowed to settle in the supply-cisterns, are next run into the boilers for evaporation. These are long cisterns, built of brick, and secured by puddle, arched over. They generally have a length of 60 feet, a breadth of 6, and a depth of 4 feet, and are capable of evaporating from 4,500 to 5,000 gallons

in 24 hours. The furnace is placed at one end of the boiler, nearly on a level with the surface of the liquor when full, and a powerful chimney being placed at the opposite end, a strong draught is created, which, sweeping the flame and heated gases over the surface of the liquor, produces a very high temperature, and rapid evaporation takes place. The furnace is fired incessantly for 8 days, and the boiler is constantly supplied with liquor from the supply-cisterns till the last night, when a supply of mother-liquor is run in, which, depositing no sediment, as the fresh liquors do, by boiling, the whole liquor in the boiler is allowed at least 12 hours to settle and become clear. When the last supply of mother-liquor has been added, a quantity is taken out of the boiler for the purpose of ascertaining its value. This being boiled up to the proper strength with muriate of potash, a measured quantity having been previously tested with different quantities of muriate of potash, affords on the following morning a crop of alum crystals, varying in amount with the quality of the liquor and the muriate used; by washing, drying and weighing these, the alum-maker judges of the proper quantity of potash to be added per gallon of liquor.

This being ascertained, by gauging the boiler when ready to run off, the sp. gr. being 60° T., the muriate is weighed out and placed in the cooler, which is a stone cistern, sunk in the ground, and secured by puddle. All being prepared, the plug is removed from the boiler, and the liquor conveyed by stone gutters to the cooler, where it is allowed to run in on the top of the heap of muriate. Towards the end, it is well agitated to insure a complete solution of the muriate and a uniform state of the liquor. In four or five days, the plug of the cistern being withdrawn and the mother-liquor run off, the bottom and sides of the cooler are found lined with crystals of alum, generally some inches in thickness. This alum is called first-alum, and is removed from the cistern to the draining-stage, which is a raised platform, sloped in such a manner that the mother-liquor may easily drain from the heap. Granulation, or the forming of "alum-meal," is never practiced, as it is found to yield too small a return, and the mother-liquor, which contains a large quantity of iron-salts, cannot be so well drained from the meal, as from the firm, hard crystals.

The first-alum having been drained, is now washed, to remove the mother-liquor from it as much as possible. For this purpose, tubs are filled with second-alum-mothers, or liquor which has been used in washing in a subsequent part of the process, and the alum, placed in wooden sieves, is rinsed in this liquor and thrown on the stage to drain.

The second-alum-boiler, which is a deep stone cistern, covered with wood, is then prepared, by running in a quantity of liquor which had been previously used in washing the second-alum. Steam is then introduced until the liquor has nearly attained its boiling point, when the washed and drained crystals are thrown in, and constant agitation is kept up. This is continued till as much alum has been added as will increase the sp. gr. to 60° T., when the temperature is raised as

much as possible by the steam, which is then shut off, and the boiler being closely covered up, the liquor is allowed to remain at rest for 12 hours to allow all impurities to settle. The plug is then removed, and the clear liquor runs off to the second-alum-coolers, which, as before, are sunk stone cisterns. In these it remains for four or five days, when the sides and bottom are found lined with alum, now nearly white, to the thickness of 8 or 9 inches. The mother-liquor, which should have a sp. gr. of 26°, is now removed, and used for washing the first-alum, as already described; and the crystals, being broken up, are removed to the roaching-stage, to be again washed with pure water, and drained, previous to the finishing process, which is called *the roaching*. The roaching-pan is a large leaden cistern, generally of many tons' weight, closely covered over. Into this, a large quantity of steam is blown, and the alum is shoveled in to meet it; a solution then takes place rapidly, without the addition of any water. The solution having reached 96°, the temperature is raised as high as possible, generally to 224° F., and the steam being shut off, the pan is closely covered up, and allowed to remain in a state of rest for 4 or 5 hours, or until the temperature has fallen to 200°. The water which had been used for washing the crystals is again used for washing the first-alum as described above. During the time that the roaching-pan is cooling, the roaching-casks are being prepared, which are large, deep, wooden tubs, lined with lead, and capable of containing two tons each of finished alum. Into these the liquor from the roaching-pan is run, and the casks are covered up, each with its own lid. Being allowed to remain for 4 to 6 days, according to the state of the weather, the hoops are loosened, and the staves removed, the crust of alum being sufficient to withstand the pressure of the liquor within. After being allowed to stand in this state for two weeks longer, a hole is pierced in the bottom of each, through which the mother-liquor, called tun-liquor, sp. gr. 10°, is allowed to run off, and is removed to be used in dissolving first alum.

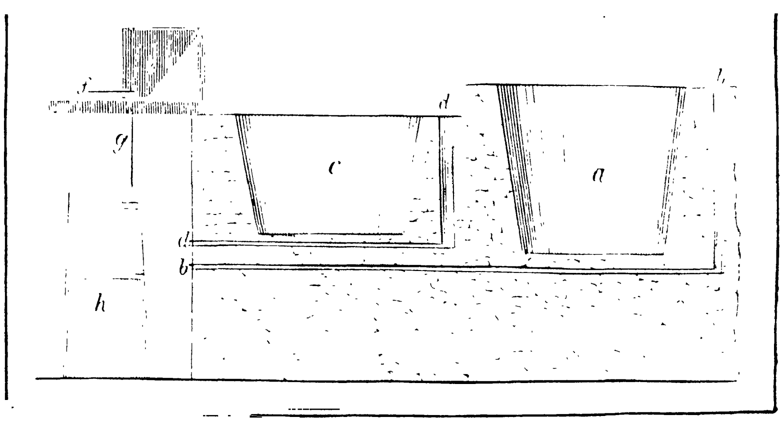
The mass of alum being now cut into square blocks of about 1 cwt. each, is ready for the market, and is either sent off in bulk, or packed in casks, as may be required.

Production of Alum from Rocks containing Alumina.—In insolated cases the sulphurous acid which is evolved in certain metallurgical operations has been made subservient to the production of alum, by causing the vapors to act upon rocks containing alumina in a manner similar to that which occurs in nature under the influence of volcanic agencies. At Linz, on the Rhine, for instance, the sulphurous acid, evolved in the process of roasting zincblende (sulphuret of zinc), is passed over copper slate and basalt, which become decomposed when sufficient moisture and air are admitted. The product is a mixture of sulphate of alumina with the sulphates of iron and copper, and these are separated in the manner indicated above. It must be remarked, however, that many rocks, like the basalts, contain soda (as much as 6 per cent.), which will give rise to a corresponding quantity of soda-alum.

From Clay.—The mode of obtaining sulphate of alumina, as first practiced by Alban and Chaptal in France, is essentially different. This is effected by the direct action of sulphuric acid upon clay (silicate of alumina and free alumina), which should only, of course, contain very small quantities of lime and iron. Plastic or pipe-clay answers best for this purpose; whatever kind of clay is used, it must always be previously burnt so as to admit of pulverization, for this reason, that fresh clay takes up the acid very much less readily than that which has been rendered porous by calcination. Another object of this calcination is to peroxidize the iron. When the clay has been ground and sifted, it is digested for several days with 45 per cent. of sulphuric acid (of 45° B. from the chambers) in a cistern which is heated by the waste heat from the calcining-furnace to about 70° C. (158° F.) Sulphate of alumina is thus formed, and the mass gradually becomes thicker by the separation of silica. In this state it is removed from the cistern, and after having been exposed for some months to the air to complete the action of the acid it is lixiviated and precipitated. Others prefer kneading the fresh clay with potashes previous to calcining, when the digestion with sulphuric acid gives rise at once to the production of alum, and the deposition of silica.

Some manufacturers employ large shallow troughs, lined with lead, and heated from below by flues, for the purpose of mixing the prepared clay with sulphuric acid; in these it is frequently turned over until the acid has combined with the alumina.* In this state the whole is removed to the stone pit *a*, Fig. 134, where it is treated with

Fig. 134.



successive quantities of water to extract the sulphate of alumina. Each ley is syphoned off into the pipes *b*, whence it is conveyed to

* An improvement has very recently been made in the above process, which consists in distributing a certain quantity of the powdered clay upon a shallow circular trough, and allowing the necessary quantity of concentrated acid to flow from a cistern above, through a number of small jets upon it, while a rouser, worked by machinery, thoroughly mixes the acid and clay together, and causes a more speedy combination than is effected on the old plan in the troughs.

evaporating-pans to be boiled down to strength. The liquor is then pumped into another similarly constructed stone pit *c*, where the requisite quantity of sulphate of potash is added. The cistern or pit *c*, is termed the precipitating-vat; the precipitated alum, which appears on agitating the solution, is allowed to subside, while the mother-liquor is syphoned off through the pipe *a* to be employed in small quantities, when not too impure, in the preparation of a subsequent precipitate. The precipitated alum, which is called alum-*powder*, is washed in the cistern *c* with successive portions of water, which are syphoned off in the same way as the mother-liquor. The pure alum-powder is then ladled into the funnel-shaped vessel *e*, where it is very economically dissolved by admitting a current of steam through the pipe *f*, and the saturated solution of alum flows down the pipe *g* into the crystalizing frame *h*.

The evaporation and concentration of the various liquors are conducted in boilers, lined with lead, by means of steam pipes circulating round the boilers, as shown in the drawing, Fig. 135, at *i*. This mode of evaporation is found to be best adapted for such liquors, as well as more economical.

From Felspar.—According to a former proposition of Sprengel, which has recently been carried out by Turner, felspar ($KO,SiO_3+Al_2O_3,3SiO_3$) is decomposed by the aid of sulphate of potash in a reverberatory furnace, and subsequently fused into a glass with as much carbonate of potash. This exceedingly alkaline glass is decomposed by boiling water into a soluble silicate of potash, and an insoluble silicate of alumina and potash. The latter is converted by boiling sulphuric acid into alum and free silica; the former can also be turned to account by removing its silica by means of lime. As no iron is present in these operations, salts of soda and soda-felspar (albite) might also be employed.

Fig. 135.

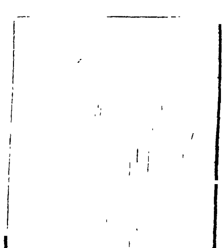
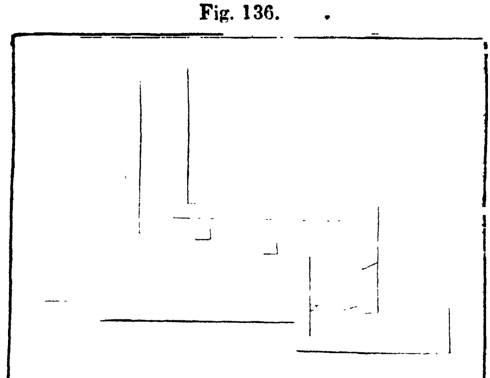


Fig. 136.



The furnace which Turner employed is known in the potteries as a "grit-furnace," and is shown in the sketch, Fig. 136. It was well adapted for this purpose, but Turner found in working out his patent on a large scale, that the great heat required was a serious drawback.

Tilghman's recent patent for extracting the potash from felspar as a sulphate or muriate, holds out the prospect, however, of being able to dispense with such a high heat.

Alum may likewise be obtained by treating a mixture of two parts felspar and three parts fluorspar with sulphuric acid at a low red heat, until the vapors of fluosilicic acid cease to be evolved. The mass is lixiviated with water, and after the separation of a little sulphate of lime, is evaporated, and deposits an abundant crop of very pure alum.

Properties of alum.—Potash-alum parts with its water of crystallization when heated to nearly 300° C. (572° F.); the melted mass presents a pulverizable, white, porous appearance, and is converted into anhydrous or burnt alum, (*Alumen ustum*), which re-dissolves with difficulty in water, but nevertheless slowly attracts its water of crystalization again from the air. At a red heat, the sulphuric acid of the sulphate of alumina is partly expelled in an anhydrous state, and partly as sulphurous acid and oxygen, while sulphate of potash and alumina compose the residue. Ammonia-alum is affected in the same manner, but after being heated to redness, nothing but alumina is left. Both these varieties of alum have an acid reaction.

The following analyses exhibit the composition of some artificial alums:

I. POTASH-ALUM.

	Thomson	Thenard.	Vauquelin.	Graham.	Theoretical.
Potash - - - - -	9.86	10.02	10.40		9.95
Alumina - - - -	11.09	12.53	10.50	54.11	10.83
Sulphuric acid - -	32.85	26.04	30.52		33.71
Water - - - - -	46.20	51.41	48.58	45.89	45.51
	100.00	100.00	100.00	100.00	100.00

II. SODA-ALUM.

	Wellner.	Ure.	Zellner.	Graham.	Theoretical.
Soda - - - - -	6.29	6.48	6.67		6.80
Alumina - - - -	10.19	10.75	11.00	52.53	11.21
Sulphuric acid - -	35.10	34.00	34.32		34.89
Water - - - - -	48.22	49.00	48.01	47.47	47.10
	99.80	100.23	100.00	100.00	100.00

III. AMMONIA-ALUM.

	Riffault.	Forchhammer.	Theoretical.
Ammonia - - - - - -	"	"	3.75
Alumina - - - - - -	11.906	11.24	11.34
Sulphuric acid - - - - -	36.042	35.90	35.29
Water - - - - - -	"	"	49.62
			100.00

CHINESE-ALUM, *(recently imported into this country.)*

	Richardson.
Sulphuric acid - - - - - - -	34.06
Alumina - - - - - - - -	11.38
Potash - - - - - - - -	10.44
Water - - - - - - - -	43.12
	99.00

Impurities.—The purest kinds of alum always contain a little iron; that from Liege contains $\frac{2}{10000}$; that from Gavelle, near Paris, $\frac{8}{10000}$; that from Aveyron, $\frac{11}{10000}$; and English alum contains $\frac{12}{10000}$. This admixture of iron-alum, which is easily detected by means of yellow prussiate of potash, is sufficient to deaden and impair the delicate light colors imprinted upon cloth; it can, however, be removed by re-crystalization, or, as Prussian-blue, by the addition of the yellow prussiate. Only the Roman alums—this name being given in commerce to all varieties that are exported from Italy—are sufficiently pure for immediate use, and are highly prized on account of the minute quantity of iron which they contain, although their outward appearance would naturally lead to a contrary assumption. These varieties consist of small disconnected crystals, covered externally with a reddish mud, composed of ferruginous earth;* this mud, however, is not dissolved with the alum, and the small portion of persulphate of iron contained in the soluble iron-alum does not exceed $\frac{1}{2000}$. Alum of this character only produces a blue precipitate with yellow prussiate of potash after standing for several hours, whilst ordinary alum affords a precipitate in a few minutes. Roman alum is generally crystalized in the form of octahedrons, but cubical crystals occasionally occur, and have given rise to the name *cubic alum.*

The composition of this alum, and the circumstances that concur during its formation, have not been minutely investigated, but its reactions differ in some respects from common alum. When the cubical crystals of Roman alum are dissolved in water at a temperature ranging between 36° and 40° C. (96° to 104° F.), and the salt is re-crystallized, it is again obtained in the form of cubes; these are produced with greater certainty when the solution is submitted to spontaneous evaporation. At a higher temperature, the solution becomes turbid by the separation of basic alum, and the clear liquid then affords octahedral crystals. The production of Roman cubical alum is therefore probably due to the presence of an excess of alumina in the crystalizing alum-liquor. By digesting octahedral alum, however, with hydrate of alumina, and allowing the solution to evaporate spontaneously, exposed to the air, cubical crystals are obtained with the simultaneous separation of a basic salt of alumina, which have the same acid reaction, and the same properties as ordinary octahedral alum.

* This earth is said by some to contain no iron.

Neutral alum.—Instead of adding alumina to ordinary alum, a similar result may be obtained by removing sulphuric acid from it by means of an alkali. The same compound is actually formed when a solution of alum is treated with carbonate of potash, as long as the precipitate, which is formed at first, is dissolved. This substance is known in the arts as *neutral alum*, and is essentially a solution of ordinary alum with a certain proportion of basic sulphate of alumina. A solution of this kind is naturally much more prone than unaltered alum to yield its excess of alumina to the vegetable fibre in the print works, and in this case, no sulphuric acid is liberated to act injuriously upon the texture of the cloth.

Commercial sulphate of alumina.—It has already been stated that the presence of an alkaline sulphate is not essential in those processes for which alum is employed, it is indeed rather objectionable than otherwise. A substance has recently been introduced into commerce under the name of alum, which is very much more effectual than the crystaline salt; it occurs in thick four-sided plates, about an inch in thickness, which are white, and partially translucent, dissolve perfectly in water, exhibit no trace of crystalization, and possess the peculiar taste of alum in a more marked degree than even alum itself. This substance is entirely free from iron. The process, for which Wiesmann has taken a patent, consists in treating clay with sulphuric acid in the manner already described, and differs only in adding no sulphate of potash to the solution of sulphate of alumina, but precipitating any iron that may be present by yellow prussiate of potash, and evaporating to the consistence at which the mass will solidify when cold, and then pouring it from the melting vessel.* Mohr found this substance, which is improperly called alum, to be perfectly free from iron, and to contain 13.91 alumina, 36.24 sulphuric acid, 49.60 water, and 1.5 sulphate of potash, which latter constituent is due to the small amount of potash naturally existing in all clay. This composition corresponds exactly with 7.1 per cent. of common alum, and 92.9 per cent. neutral sulphate of alumina ($= Al_2O_3,3SO_3 + 18$ aq.). The only objection that can be raised to the practical application of this substance is, that its form precludes the possibility of estimating its purity by the outward appearance, which is so very easily done with alum, on account of the distinct crystaline form which it assumes.

Wiesmann's process for preparing a pure alum or sulphate of alumina free from iron has been found the most effectual and economical, and consists, as practiced in this country, in agitating the solution of sulphate of alumina in a large wooden vessel *a*, Fig. 137, with a solution of prussiate of soda. After allowing the bulk of the precipitated Prussian-blue to subside, the supernatant liquor is run off into the wooden vessels *b*, *b*, *b*, where it remains until perfectly clear and free from precipitate. The clear liquor is then treated in the manner already described. The precipitated Prussian-blue is

* Compare note, p. 175.

Fig. 137.

repeatedly washed with water in the vessel *a*, to remove all traces of the sulphate of alumina, and the washings are run off into some of the vessels *b* for the above object.

The Prussian blue is now treated with a ley of caustic soda, to separate the iron, and thus the same precipitant serves for a long period with very little loss.

The following is an analysis of a sample of commercial sulphate of alumina from which the iron had been removed by prussiate of soda:

	Richardson.
Sulphuric acid	35.95
Alumina	14.25
Lime	traces
Magnesia	traces
Chlorine	traces
Water	48.05
	98.25

The refuse which remains after lixiviating the crude sulphate of alumina, always contains some sulphuric acid, which probably exists as a subsulphate, and resists the solvent action of the water. Two samples furnished the following results:

	Richardson.	
Silica	41.85	39.05
Alumina, with traces of peroxide of iron	18.40	25.55
Sulphuric acid	4.45	8.47
Sulphate of lime	4.01	traces
Water	29.53	27.50
	98.24	100.57

A patent has been secured by Mr. Wilson to employ the shale of the coal formations, instead of clay, for the manufacture of alum. The only difference in the mode of treatment consists in the first operation. Instead of calcining the shale in a reverberatory furnace, it is burnt

in large heaps in the open air, when the series of operations, already described, are followed. Mr. Wilson's plans and calculations do not, however, appear to have been successful.

OF GREEN VITRIOL, OR COPPERAS.

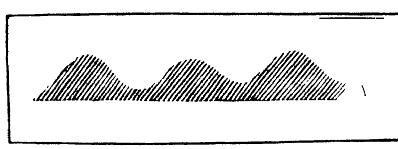
It will have been evident from the foregoing section, that the production of alum from alum-ore was an indirect process, and mainly depended upon the prior formation of protosulphate of iron, which is altogether unconnected with the presence of alumina. When mineral masses, of a similar nature to the alum-ores, containing, however, no alumina, decay under the influence of the atmosphere, protosulphate of iron alone is produced, and of course no sulphate of alumina. Upon this fact the operations of the copperas factories are founded, and these are for this reason very similar to those carried on in the alum works. Amongst the crude materials employed in the copperas works, belong not only the carboniferous deposits which are impregnated with the sulphurets of iron, but also iron pyrites itself, and many less massive varieties, like cock's-comb pyrites, which when exposed in loose heaps to moist air, absorb oxygen, and are converted into green vitriol.

The composition of iron pyrites is shown in the following analyses:

	Bucholz.	Hatchett.	Berzelius.
Iron - - -	49	47.85	46.08
Sulphur - - -	51	52.15	53.92
	100	100.00	100.00

These ores, which are obtained from the coal formation, are collected together in heaps or walls *A*, Fig. 138, in a manner similar to that pursued with the alum-ores, and are watered from time to time, to facilitate their decomposition. The fluid which runs from the heaps, collects on the water-tight foundation, and is conducted to a basin, whence it is removed for boiling if sufficiently saturated, or returned to the heaps when the contrary is the case.

Fig. 138.



Pyrites, which is not spontaneously decomposed by exposure, like that which occurs in the older geological formations, is roasted previously to exposure, either in close vessels or in contact with air. In the former case about 10 per cent. of flowers of sulphur is obtained, and protosulphuret or $\frac{8}{7}$ths sulphuret of iron remains; in the latter case, the sulphur is burnt, and forms sulphurous acid, leaving protosulphuret of iron with more or less green vitriol as residue. This mode of treatment has been noticed in vol. i. p. 221, when speaking of sulphur and sulphuric acid.

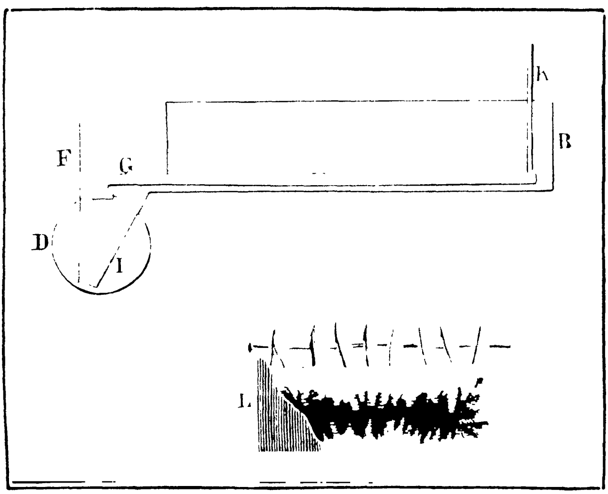
These residues of the burnt ores are very easily decomposed, and are treated in precisely the same manner as the ores which are spontaneously acted upon by the atmosphere.

Spence has patented this plan for employing the residue of the pyrites as it comes from the furnaces of the sulphuric acid manufacturers.

When the ore has been completely decomposed, the whole of the vitriol must be extracted from it by lixiviation, provided the rain or the water that has been added has not entirely exhausted it, and this part of the operation is similar to that practiced with the alum-ores, as is also the process of boiling the crude ley.

The following is a very economical plan for evaporating the large quantities of liquid obtained in such works; *B*, Fig. 139, is a section

Fig. 139.

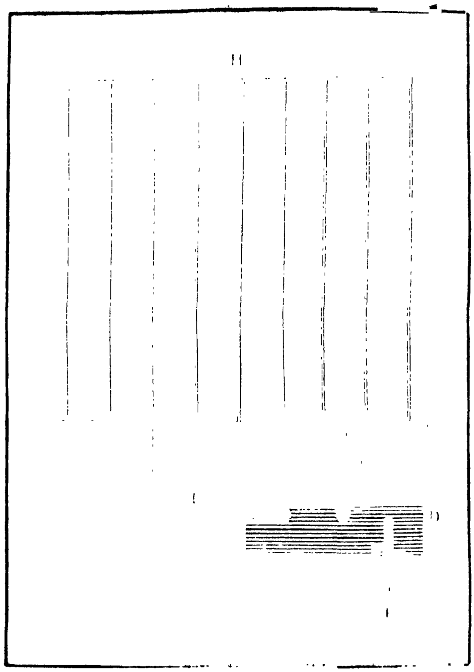


of the lead pan used for this purpose, which is about 30 ft. by 40 ft., and 5 ft. deep. Fig. 140 is a ground plan of the whole arrangement. Heat is communicated in the usual way to the boiler *D*, which is kept constantly full of water by a supply from the cistern *E*, through the pipe *F*. The hot water escapes from the top of the boiler by the pipe *G*, and flows through the entire length of the pans into the receiving-pipe *H*, whence it returns by the pipe *I*, which descends to the bottom of the boiler. *K* (Fig. 139) acts as a safety-valve.

L, Fig. 139, represents a crystallizing vat, with masses of crystals adhering to the wooden sticks which are suspended in the liquid. They are generally about 16 ft. square and 6 ft. deep.

Another plan for manufacturing sulphate of iron was patented by Mr. Gregson, and carried out into practice at Newcastle. He employs ground slag, from the iron balling-furnaces, made into a thin paste with water, and an equal weight of the oil of vitriol of commerce, previously diluted with its own weight of water. The action

Fig. 140.



is very rapid, but the sulphate of iron which is obtained has been hitherto only employed for the manufacture of Venetian-red, in consequence of some unexplained difficulties attending its crystalization. This patent is very ingeniously combined with the manufacture of Epsom salts, &c.

When the copperas has been boiled for some time, the gypsum and basic persulphate of iron are deposited in such quantities as to render a clearing process necessary before the final boil is given to the ley. The workmen are in the habit of adding pieces of old iron to the crude-ley-cisterns, but more especially to the boiling-coppers and clearing-vessels. In this manner the amount of copperas is increased by the saturation of the free sulphuric acid, and the peroxide of iron which has been formed is partly reduced to the state of protoxide (Fe_2O_3 and $Fe{=}3FeO$), but what is of more importance in all cases where the ley contains sulphate of copper, the iron is substituted for the copper which is precipitated in the metallic state. This process, therefore, which is sometimes undertaken with a view to obtain copper (Cementkupfer) from solutions containing the sulphate of that metal and green vitriol at the same time, is a means of purifying the copperas from a constituent which may sometimes prove prejudicial to the purposes for which it is employed, and which cannot be separated by crystalization.

The following sketch, Fig. 141, represents a section of a heater

Fig. 141.

for dissolving the old iron and concentrating the copperas liquor. These heaters are large leaden pans, capable of holding from 15,000 to 30,000 gallons of liquor. *a a* is the leaden pan cased in fire-bricks *b b*, and heated by flues underneath and at each side *c c c c*. Masses of old gas retorts *d d d*, are placed upon leaden supports *e e e*, so that any deposit may fall to the bottom of the pan and preserve the surface of the iron as clean as possible for the action of the acid in the liquors. For a similar purpose, the leaden vessels *f f f*, pierced with holes and filled with iron borings or turnings *g g g*, are suspended by leaden supports from a joist *h*, resting upon the side walls.

A sample of refuse or deposit which had collected upon the bottom of a heater, and which had been exposed to the oxidizing action of the air, was found to consist of:

	Richardson.
Peroxide of iron	38.05
Lime	5.07
Magnesia	trace.
Sulphuric acid	36.10
Chlorine	trace.
Antimony	trace.
Arsenic	trace.
Sand and carbonaceous matter	12 72
Moisture	6.50
	98.44

By digestion in water, this residue furnished 49.76 per cent. sulphate of peroxide of iron, so that the composition is probably, as follows:

Sulphate of lime - - - -	12.31
Sulphate of peroxide of iron - -	49.76
Sulphuric acid 3.98 } Peroxide of iron 13.17 } - - -	17.15
Insoluble matter - - - -	12.72
Water - - - - - -	6.50
Magnesia, Antimony, } Arsenic, and Chlorine } - - -	trace.
	98.44

This residue is generally sold as "black copperas," but it is obvious, from the above analysis, that it would be much more profitable to lixiviate it in hot water, and add the solution to the original liquors in the heater to deoxidize the peroxide of iron, and thus save upwards of 86 per cent. of its weight of pure copperas.

In some instances, silver and gold are found in the residuum of these manufactories, and in one case where a pyrites, holding a small quantity of copper, was employed for the production of sulphuric acid by roasting at a low temperature, so as to leave the sulphate of copper undecomposed, according to Mr. Cookson's patent, and then extracting the latter substance by lixiviation, the refuse from it contained in 20 cwt.

1 oz. 17 dwt. 8.0 grs. of gold,
47 oz. 15 dwt. 17.6 grs. of silver. (Richardson.)

The refuse analyzed above, and which was the product of the pyrites of the coal formation, was roasted with carbon to destroy the sulphuric acid, smelted with litharge, and the button of lead cupelled, with the following result:

0 oz. 3 dwt. 22.08 grs. of silver, and no gold per 20 cwts. of refuse. (Richardson.)

When the sediment has settled down with any metallic copper that may occur in the clearing-cisterns, the clear ley is returned to the boiler and evaporated to the point of crystalization; it is then transferred to the growing-tubs in which wooden rods or straw-halms are placed for the crystals to attach themselves to, and treated in the manner already described at page 165.

The mother-liquor may be still further evaporated, or used, for the production of red color, when it is not required for distillation in the manufactories of anhydrous sulphuric acid (vol. i. p. 242).

In some cases, and especially those where the copperas is produced by the action of sulphuric acid on iron, the whole is made into *Venetian-red.* In others, on the Continent of Europe, the copperas liquors are evaporated to dryness in iron-pans, having been previously concentrated to the proper specific gravity in leaden vessels. The salt is well dried in a reverberatory furnace, when it possesses a white color, in which state it is subjected to distillation in earthenware retorts. 100 parts yield 36 parts of fuming sulphuric acid, and 51 to 52 parts of oxide of iron. The following is the actual cost of the process in a Bohemian manufactory:

Calcined copperas 550 lbs. - - -	139.2 fr.
Coals 3124 lbs. - - - - - -	67.5
Labor, cylinders, receivers, wear and tear, &c. - - - - - -	79.8
Interest of capital, &c. - - - - -	1.17
	287.67 fr.=$53.50

Produce 200 lbs. of fuming acid=220 lbs. oil of vitriol and 286½ pounds of peroxide of iron for Venetian-red.

Spontaneous decomposition is sometimes found to have taken place in heaps of pyrites collected together by chance, and artificial measures are then unnecessary. At Rammelsberg, near Goslar, in the Hartz, for instance, the ores that were formerly considered unfit for smelting, and were composed almost entirely of pyrites, were used for filling up the excavations in the mines, and by spontaneous decomposition have become converted into a solid mass, called "*old man.*" Green vitriol is obtained from this mass in Goslar by simple lixiviation.

The following are some analyses of natural sulphates of iron:

COMPOSITION OF NATURAL PERSULPHATE OF IRON.

	Copiapo—Chili.				Kolosoruk. in Bohemia.	Modum, in Norway.	Rammelsberg, near Goslar.
	Crystallized.	Granular.	Plates.	Radiated.			
Sulphuric acid - -	43.55	43.55	39.60	31.73	32.111	32.42	13.585
Perox. of iron - -	24.11	25.21	26.11	28.11	46.736	49.37	63.854
Alumina - - -	.92	.78	1.95	—	—	—	—
Lime - - - -	.73	.14	—	1.91	.643	—	—
Magnesia - - -	.32	.21	2.64	.59	—	—	—
Potash - - -	—	—	—	—	7.883 soda	5.03	—
Oxide of zinc - -	—	—	—	—	—	—	1.232
Ox. of copper - -	—	—	—	—	—	—	.875
Silica - - -	.31	.37	1.37	1.43	—	—	2.000
Water - - -	30.10	29.98	29.67	36 56	13.564	13.13	18.454
	100.04	100.24	101.34	100.53	100 937	99.95	100.000
	H. Rose.					Scheerer.	Jordan.

Auteuil, near Paris, by Meillet.

Sulphuric acid - - - -	42.90
Peroxide of iron - - - -	53.30
Water - - - - -	3.96
	100.16

COMPOSITION OF NATIVE PROTOSULPHATE OF IRON (OR GREEN VITRIOL).

Campsie, near Glasgow.

	Berthier.	Philips.	R. D. Thomson.	
Sulphuric acid - -	34.4	30.9	35.600	28.635
Protoxide of iron -	12.0	20.7	13.560	19.935
Alumina - -	8.8	5.2	7.127	2.850
Magnesia - - -	0.8	—	—	—
Water - - -	44.0	43.2	43.713	48.580
	100.0	100.0	100.000	100.000

Green vitriol forms pale-green distinct crystals, containing 7 equivs. of water. It is never pure as prepared in large quantities; although the neutral persulphate of iron and sulphate of alumina remain dissolved in the mother-liquor, other sulphates crystalize easily with the copperas; amongst these are the sulphates of copper, zinc, and tin, when the ores contained the corresponding sulphurets, and not unfrequently sulphates of lime and magnesia accompany the crystals of copperas. Arsenious acid also sometimes occurs, when arseniurets were present in the pyrites, and alumina is introduced by the enclosed mother-liquor. 100 parts of water dissolve, according to Brandes and Firnhaber, the following quantities of crystalized protosulphate of iron:

Temperature C.	10°	15°	25°	33°	46°	60°	84°	90°	100°
Sulphate dissolved	60	96	114	151	227	263	270	370?	333

The solution of this salt dissolves a large quantity of binoxide of nitrogen; a property which it shares in common with all the salts of the protoxide of iron.

The crystals become brown when left long exposed, in consequence of an incipient decomposition, during which basic persulphate of iron is formed. Green vitriol is isomorphous with sulphate of copper, and is enabled consequently to crystalize in all proportions with that salt. The crystals containing the two salts are of a bluish-green, and the blue tint becomes more intense as the amount of copper increases. The copperas prepared at Salzburg and Admont is of this kind, and is prized on account of the copper which it contains, this being desirable in some of the applications that are made of it. The method of removing the copper has already been mentioned.

When the crystals are formed from acid solutions (as in Sweden and England), they exhibit a more green blue color, and are often covered with a white or yellowish powder; from neutral solutions (as the German), the copperas crystalizes in turbid dull-green crystals, which remain very dry, whilst those obtained from ley rich in peroxide of iron (like that of Muskau) are much contaminated with the latter substance, and are consequently subject to be constantly moist (fat).

According to Dumas, the variations in commercial copperas are due to a peculiar double salt of the prot- and peroxides of iron, which is still little known. Two varieties are constantly met with, the one of which is of a grass-green color and in large crystals, the surfaces of which are not liable to be coated with an ochreous deposit; the other, which is of a clear green, is habitually mixed with effloresced portions, or is covered with sub-sulphate of peroxide. The former contains both prot- and peroxide, and the latter is simply a salt of the protoxide. In passing to the state of a double salt, this becomes oxidized on the surface. The dark colored salt is generally less acid than the other. To correct the color of the latter, it is often watered with a solution of common salt or of tannin. But these substances, in changing its color, do not alter its state of acidity.

Sulphate of iron is also made by the action of sulphuric acid upon iron, iron-slags, &c., in which case, the experience of Bérard has shown that the most beneficial action is produced by using acid of 1.21 sp. gr., and maintaining the liquor at that strength. When the mother-leys are mixed with the acid, the specific gravity of acid and ley ought not to exceed 1.283, nor be lower than 1.261, and he further recommends that the fresh acid ought to be of 1.32 sp. gr. when mixed with its own volume of mother-ley, and as high as 1.455 when two-thirds of the latter are employed.

M. Lefort has investigated the composition of the different kinds of copperas employed in France for producing a black dye, and also for mixing with corn which is to be sowed, and which are known under the names of *vitriol Salzbourg* and *vitriol mixte Chypre.*

The former of these salts was generally supposed to be a mixture, in variable proportions, of the sulphates of iron and copper, and the latter to be a mixture of the sulphates of iron, copper, and zinc.

The *vitriol Salzbourg* is manufactured at Paris, Vienne (in Dauphiné), and Bouxwiller, and varies very much in composition in the different manufactories. Its value is in proportion to the quantity of sulphate of copper which it contains.

It is prepared by roasting iron and copper ores exposed to the atmosphere, or by oxidizing copper and iron by heat, and dissolving the oxides in dilute sulphuric acid. The quality of the product is very much influenced by the amounts of iron and copper in the mixture, and by the degree of concentration of the liquors, which is kept secret in the manufactories. The mixed sulphate from Bouxwiller is very superior to that manufactured at Paris, and is always of uniform composition, and has a crystalline form peculiar to itself, while the Parisian sulphate is very variable in composition at different times, and is always in the form of green vitriol.

The compound sulphate of Bouxwiller was found, on analysis of several specimens, to correspond very nearly with the formula,

$$CuO,SO_3+3(FeO,SO_3)+28HO,$$

or with the following:

	In 100 parts.
4 equivs. sulphuric acid - - - -	28.76
1 oxide of copper - - - - -	7.11
3 protoxide of iron - - - -	18.91
28 water - - - - - -	45.22
	100.00

By mixing 1 equiv. of sulphate of copper with 3 equivs. of sulphate of iron, the compound sulphate was obtained in quadrangular prisms with oblique base, perfectly similar to those of commerce.

100 parts of water at 7° C. dissolve 75 parts of the salt.

The *vitriol mixte Chypre* is a double sulphate of copper and zinc, which is used in the south of France for mixing with corn which is

to be sowed, the action being generally attributed to the sulphate of copper.

This salt is brought into commerce from the mines of Chepy, where it is probably derived from the hydrated carbonate of copper and zinc, or buratite, lately discovered by M. Delesse in these mines. The double sulphate occurs in oblique rhombohedral prisms of a clear blue color.

The analysis of the salt yielded a very close approximation to the formula,

$$CuO,SO_3+3(ZnO.SO_3)+28HO.$$

Or,

	In 100 parts.	By experiment.
4 sulphuric acid - -	27.99	28.10
1 oxide of copper -	6.92	6.27
3 oxide of zinc - -	21.19	19.48
		1.83 protoxide of iron.
28 water - - - -	44.00	44.23 water.
	100.00	99.91

This salt may be formed artificially by dissolving together 1 eq. of sulphate of copper with 3 equivs. of sulphate of zinc, and crystalizing over sulphuric acid. When equal equivalents of the two salts are dissolved together, two-thirds of the sulphate of copper separate in the first instance, and, subsequently, the above double salt.

The commercial sulphate becomes covered, when exposed to the air, by a basic sulphate of iron.

100 parts of water at 8° C. dissolve 80 parts of this salt; boiling water dissolves it in all proportions.

A large number of vitriolic products are manufactured in Bohemia, from the argillaceous shales and lignites containing iron pyrites, and it may be well worth while to call attention to the plans adopted there for converting the unsaleable copperas into anhydrous sulphuric acid. Of the method for extracting the sulphur in the first instance from the dodecahedral pyrites, and for converting it into sulphuric acid, we shall not treat at present, but refer to vol. i. page 217, nor shall we dwell upon the plans for converting the roasted pyrites into protosulphate of iron by exposure to the air and water, but shall confine our attention to the lixiviation of the aluminous schist, or more properly the pyritous schist worked in the manufactory of Weissgrün.

The following table shows the composition of these various deposits according to the analyses of M. Anthon:

LOCALITIES.

Localities.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.
	Schists from Weissgrün near Radnitz.				Rzeschdlau, near Beraun.	Darowa, near Radnitz.	Boschkaw, near Pilsen.	Hromitz, near Plass.	Unter-Brzezi near Plass.	Kozoged near Plass.				Lednitz.	Unter-Brzezi near Plass.
PORTION SOLUBLE IN WATER.															
Protosulphate of iron	"			0.70	"	traces	"	1.60	0.50	"	"	0.80	"	"	"
Sulphate of lime	0.50	2.80	1.20		0.90	1.00	0.80			0.90	0.20		0.50	0.40	0.60
Sulphate of magnesia				"	"	"	"	"	"		"	"	"	"	"
PORTION INSOLUBLE IN WATER.															
Iron pyrites	6.62	31.53	12.37	9.92	8.56	14.50	7.43	11.58	5.47	8.10	8.34	14.33	10.94	13.72	0.79
Peroxide of iron	1.83	2.17	0.76	1.85	0.40	2 42	2.21	0.16	1.20	1.15	2.20	0.64	1.27	1.34	3.48
Alumina	3.60	2.40	3.50	4.00	2.10	2.80	3.10	1.20	1.00	2.30	0.07	1.30	1.50	1.20	5.40
Silica	81.40	55.96	74.90	75.90	81.23	71.21	78.63	75.70	85.10	81.44	80.80	73.40	78.40	72.70	86.60
Carbon	5.90	4.99	6.09	6.10	6.77	6.84	6.37	8.40	6.10	5.20	7.70	8.80	5.60	9.30	1·10
Lime															
Copper	0.15		1.18	1.53	0.04		1.46	1.36		0.91	0.69	0.73	1.79	1.34	2.03
Arsenic		0.15				1.23			0.63						
Loss															
Silenium	"		"	"	"		"	"		"	"	"	"	"	"
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Specific gravity	2.75	3.14	2.76	2.75	2.71	2.67	2.66	2.56	2.75	2.79	2.45	2.85	2.71	2.78	2.83

Those varieties which contain the pyrites in a minute imperceptible state of division are more appropriate for the purposes to which they are here applied than such as contain large crystals. None of the varieties are roasted previous to exposure. The schists are exposed at Weissgrün in long ridges, 26 feet high, upon a surface of clay prepared for the purpose, and slightly inclined. They are lixiviated every 2 months, and each lixiviation lasts about 10 days. The liquors are generally sufficiently saturated as not to require being returned to the ridges; they show a density of 10° B. (= 1.071 sp. gr.).

These liquors are evaporated to 40° B′ (= 1.380 sp. gr.) in a series consisting of 3 pans of the same length, arranged in the manner shown in Figs. 142, 143 and 144.

Fig. 142.

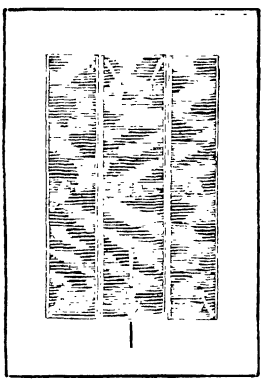


Fig. 143.

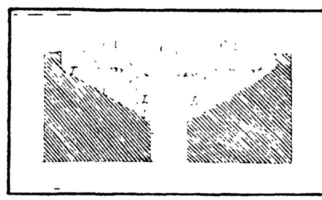


Fig. 144.

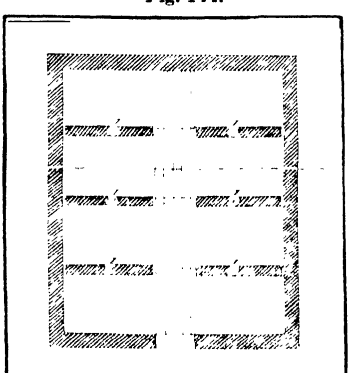
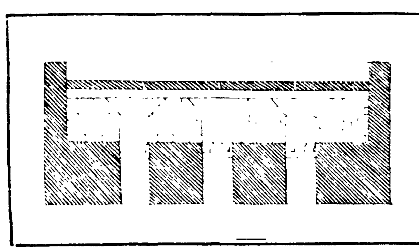


Fig. 145.

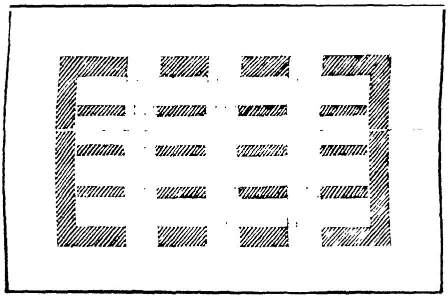


The pans are rectangular and flat-bottomed, about 9 feet in length; the two outer pans, $C_1 C_3$, Fig. 142, are placed on the same level, and are about 2 feet wide and 4 inches deep; the middle pan C_2 is about 3 feet wide and 4 inches deep, and is placed about 2 inches lower than the other two (Fig. 143). The pans are supported and protected from the flames by bars of iron, *f*, placed in juxtaposition. The

grate extends the whole length of the pans. The liquors to be concentrated flow continuously into the lateral pans, C_1 and C_3 (Fig. 142), from the corners *a a'*, and pass through these at the angles *c c'*, into the pan C_2, and flow off through the tube *d*, in the middle of the opposite side. A deposit of sub-sulphate of iron is formed during the evaporation, and is removed from the pans every 2 hours. These leaden pans last on an average 7 or 8 months. The liquors which have thus been concentrated to 40° B. (1.380 sp. gr.), flow into two flat pans placed at the same level with the preceding, where they are concentrated to 45° B. (1.455 sp. gr.) From thence they are allowed to run into hemispherical cast-iron pans, where they are brought to the consistence of a syrup after 24 hours' evaporation. The syrup is then taken up with iron scoops, and conducted by wooden channels to a cast-iron bed, Fig. 145, heated by three fires, where it is evaporated to dryness.

This plate is constructed of 8 parts, each of which measures a square meter (meter=3 f. 3 in.), and which are simply placed one by the side of the other, resting upon five bars of iron which are supported by the sides of the fire-places and by the walls, Fig. 146. The arrangement is heated by three grates below the iron plate, and the flame and smoke escape on the opposite side to the grate-doors. The syrup is completely desiccated in about 80 hours; it is then called *vitriolstein*, and only contains from 4 to 5 per cent. of water. Analysis showed that for every 9½ parts of peroxide of iron, it contained only 1 part of protoxide.

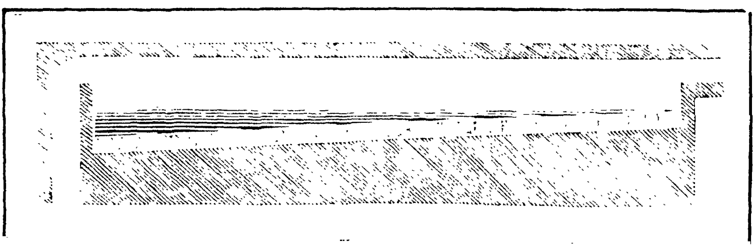
Fig. 146.



The most concentrated liquors from the ridges are allowed to crystalize, and copperas is thus obtained. The mother liquor is then saturated with carbonate of potash in order to obtain a crop of alum crystals.

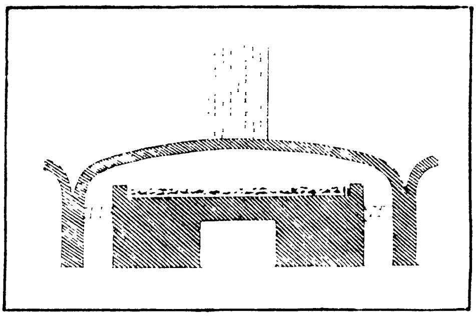
In Hromitz, the liquors are partly concentrated in a series of evaporating vessels somewhat similar to those used at Weissgrün, until

Fig. 147.



they have attained 40° B., and are then brought to the consistence of a syrup, partly in hemispherical cast-iron vessels, partly in reverberatory furnaces, shown in section at Fig. 147; and which resemble the furnaces employed in the neighborhood of Paris for the manufacture of sulphate of alumina. In these furnaces, the soles of which slope towards the fire, the liquors are concentrated to 40° B., and having been brought to the state of syrup in the round iron pans, the mass is allowed to cool and solidify in earthen vessels. From these it is broken out with axes, and transferred to a rectangular brick reverberatory furnace, Fig. 148, which is heated by two fires, in order to be

Fig. 148.

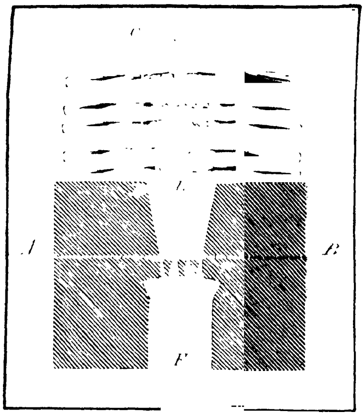


perfectly desiccated. The arch of the furnace is very low, the door is closed during the operation, but two small apertures are left, at the side of it for the admission of air. The charge is spread uniformly over the sole of the kiln, and is frequently turned over with rakes. Each operation lasts 6 hours. The dry product (*vitriolstein*) is then dispatched to Radnitz for conversion into fuming oil of vitriol. This process consists in the dry distillation of the vitriolstein. The pots in which the distillation is effected are constructed of refractory stone-ware, and after being baked in a kiln, upon the premises, are about 9 inches long, 2.4 in diameter at the bottom, 4.2 at the middle, and 3 inches at the mouth: they are about 0.4 inches thick in the sides. Before being used they are covered with a lute which is easily fritted by the action of the fire. The receivers are of much the same shape, but longer and narrower at the mouth. The upper row in the furnace is occupied by a single range of pots, twenty-eight inches in length.

The gallery-furnace for the reception of the pots is rectangular in section, and is composed of two parts essentially distinct. The lower part is built of massive masonry, enclosing the ash-pit and the grate, which extends the whole length under the range of pots; the upper part consists of two vertical walls of perforated brick-work, which form the sides of the furnace and support the pots. This latter portion demands frequent repair.

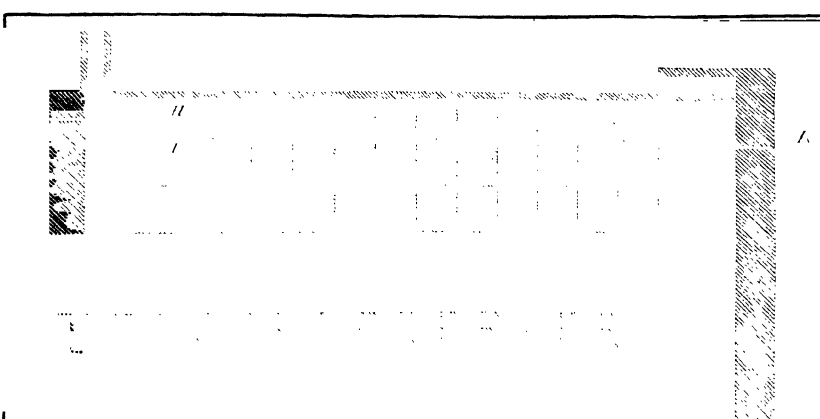
Fig. 149 represents a front vertical section, and Fig. 150 a longitudinal section of the furnace.

Fig. 149.



It encloses 4 tiers of the smaller sized pots, arranged with their bottoms in contact, and an upper tier of long pots, which extend from one side of the furnace to the other, and are open at both ends. The whole, therefore, contains 288 pots; 32 large, and 256 small. The long sides of the furnace are divided into squares by vertical and horizontal bricks of the same dimensions, and 4 pots are placed in each square, separated from each other by small bricks, the interstices being luted with refractory clay. The arch of the furnace is constructed of flat bricks, simply placed alongside of each other, and cut sloping at their extremities, to allow the flame to pass. A small chimney is sometimes built to the furnace, but it is more frequently without. The pots are charged with the vitriolstein, previously broken up with a hammer, by means of a semi-cylindrical spoon, each pot receiving 2 spoonfuls. The coal for the first charge is then ignited below the grate, and is thrown upon the grate at the expiration of about an hour or an hour and a half. The fire being carefully regulated by opening or shutting the doors, at the end of 4 hours the lower tier of pots is brought to a dark red heat. The receivers are successively introduced into the pots and luted, those of the second layer resting immediately upon the first, and a wooden support being introduced between the second, third, and so on, as

Fig. 150.



shown in Fig. 150. The receivers are slightly inclined, and a small quantity of water is placed in each; this is sufficient to receive the acid from 4 consecutive distillations, after which it is in the state of concentration required in commerce. The fire is gradually increased, and after from 30 to 36 hours, no more acid is evolved from the upper tier of pots, and the distillation is finished. The whole is then allowed to cool for 12 hours, and the receivers being removed, the colcothar is taken from the pots. This contains about 6½ per cent. of sulphate of lime, and amounts to about 30 or 35 per cent. of the vitriolstein employed.

The pots are now examined by the sound which they emit when struck; the broken ones removed and being replaced by fresh pots, the distillation is recommenced.

Each operation lasts about 48 hours, and three are completed in a week. From 47 to 50 per cent. of the vitriolstein is obtained in fuming sulphuric acid; 5 parts of coal are consumed for 1 of vitriolstein distilled. About 30 pots and 3 receivers are replaced after each distillation, which is equivalent to about 10.42 and 1.04 per cent. respectively.

GROUP III.

CLAY WARES. POTTERY AND PORCELAIN.

Of Clay.—Amongst the various deposits which have succeeded the formation of the primitive rocks upon the surface of the globe, there are certain earthy strata of very considerable extent, composed chiefly of silica and alumina, partly in combination and partly in mere mechanical mixture, with other less prominent and essential ingredients. These strata are characterized by the very minute state of division of their particles, and their want of firm connection or solidity. It is to this peculiar structure that the most valuable property of clay must be ascribed, that is, its plasticity or the property of forming a dough with water, sufficiently soft to take the most delicate impression from a mould, and so deficient in elasticity that even the slightest indentation is lasting and persistent.

By far the greater number of clays are so intermingled with substances foreign to them in their original localities, or have been primarily derived from such compound species of rock, or, lastly, have been so very far removed, by the agency of water, from the sources of their different constituents that it is next to impossible to trace back the course of their formation to its very commencement. Although the clays may be viewed in general as the remains of certain rocks, which have been decomposed by various agents, chiefly atmospheric, which have, in a word, been *weathered*, yet there are few cases in which the production of clay has occurred in the immediate locality of the rock whence it is derived, and in such a simple manner as to enable its origin to be traced in all particulars, and established indubitably by chemical facts. One of these cases, however, has occurred with the so called *porcelain-clay* or *kaolin*, which is found in a primitive position surrounded by the rocks from which it has sprung, offering an object of as great interest to the geologist as to the manufacturer; to the former as an instance of clay in its most pure and original form, the prototype, as it were, of all the clays; and to the latter as the chief material for the production of porcelain. The highly complicated problem relating to the nature and mode of production of kaolin has, however, at length been deciphered with great success at the cost of much time and trouble.

It was first ascertained that all species of kaolin were produced by

the action of the atmosphere upon certain minerals belonging to the felspathic class, or nearly allied to it, as spodumene, porcelain spar, &c., which, as is well known, are constituents of the most extensively diffused rocks, viz., granite, gneiss, syenite, the porphyries, &c.

The varieties of felspar, however, are combinations of a neutral silicate of alumina (in which one portion of the alumina is sometimes replaced by oxide of iron), with the silicate of a base which may at different times be potash, soda, lime, magnesia, either together or singly, and the general formula for which is: $M_2O_3,3SiO_3+MO,SIO_3$, in which M represents 1 equivalent of the metallic element.

All the porcelain-earths contain, in addition to the real clay (the *plastic* constituent, as it is generally called)—consisting of a combination of silica, alumina and water, and forming the basis of all clay—much undecomposed debris of rock, besides silicates of the earths (magnesia lime) and free silicic acid, which can only be very imperfectly separated from each other by mechanical agency, for instance, by suspension in water and subsidence. The rocky debris may be composed of such minerals as are capable of forming porcelain earth, but which have not yet been sufficiently disintegrated (portions of felspar, for instance, of which there is 16 per cent. in the porcelain earth of Limoges), or it may consist of other minerals which are not capable of such a transformation, and are therefore in no way concerned in its formation, but like the silica, which is contained in the form of quartz sand in the mother-rock, are left undecomposed and mixed with the porcelain-earth. Independently of this, which constitutes the chief part of the silica that cannot be decomposed by the ordinary wet reagents, the porcelain-earth contains another portion of silica, of quite a different origin. This latter is derived from the silicates of the more powerful bases (not alumina) which are a product of the disintegration itself, and which part with a portion of their bases to the more powerful acids. Silica separated in this manner is distinguished by its solubility.

When porcelain-earth is examined, this soluble silica must consequently be first removed, as in the future operations it would no longer be able to be distinguished from that portion which is in combination with alumina. The earth may be boiled with this object in view for 1 or 1½ minutes, with a solution of caustic potash of 1.075 sp. gr. (containing 20 per cent. of potash), (Brogniart and Malaguti). The amount of real clay may then be completely extracted from the residue by boiling it successively with sulphuric acid and caustic potash. The acid then dissolves the alumina (with traces of silica), and leaves the silica in a state in which it is easily dissolved by potash. In this manner the silica is held in solution by the potash (the undecomposed minerals being left as residue), and the alumina by the sulphuric acid (besides the earths and alkalies when these are present) which together make up the aluminous compound of which the porcelain-clay is composed. In far the greater number of porcelain-earths this substance is composed of M_2O_3,SiO_3+2 aq. A comparison of this composition with

that of the varieties of felspar, will throw light upon the chemical process concerned in the production of porcelain-earth.

Thus felspar - -	=	$M_2O_3 + 4\ SiO_3 + KO$	is decomposed into
Porcelain-clay -	=	$M_2O_3 + \ SiO_3$	and into an insoluble
Silicate of potash	=	$3\ SiO_3 + KO$	when the felspar contained potash,
Or silicate of soda	=	$3\ SiO_3 + NaO$	when soda was the base in the mineral.

These silicates are then subjected still further to the same decomposing agencies; the latter parts with SiO_3 and becomes soluble $NaO,2SiO_3$, whilst from 3 equivs. of the former = $3KO,9SiO_3$, the same amount of silica is separated, and there remains a compound = $3KO,8SiO_3$. It is worthy of notice that this composition $3KO,8SiO_3$ represents that of soluble potash glass.

The soluble silicate $NaO,2SiO_3$ has been found in the water of the Geyser, in Iceland, by Forchhammer. Both the soluble silicates have been removed by the agency of water, and again decomposed in a variety of ways, giving rise to opal, silicious slate and other minerals. When the felspars contain alkaline earths, these are generally found in the porcelain-earth, as will be seen by the analyses below. Several other causes besides the action of the atmosphere are now known to have taken part in the decomposition of felspar in different localities; thus Forchhammer has found that aqueous vapor at a temperature of 222° C. (432° F.), which is equivalent to a pressure of 23 atmospheres, will decompose felspar, and that the water dissolves an alkaline silicate; Malaguti and Brogniart have also shown that the same occurs under the influence of the voltaic current.

These decompositions and modes of formation explain the great discrepancies which have been observed in the composition of porcelain-earth from different localities, as also in that from the same locality, differing in the position in which it is found and in age. The soluble silica will be removed and dissolved in proportion as water has free access, and according to the time during which it has exerted its solvent influence. Thus Berthier found in the clay-like portion of the earth from Limoges, 43 per cent. silica, and 40 per cent. of alumina; whilst Brogniart and Malaguti only found 42 per cent. silica, and 34.6 alumina in the same kind of earth of a more recent deposit. The following table contains the results of 31 analyses carried out by Brogniart and Malaguti.

	Portion not plastic.				Plastic portion.				
					Silica.				
No.	Rocky residue insoluble in potash and acid.	Lime, magnesia, potash.	Lime, magnesia, soda.	Iron and manganese.	Separated by potash.	In combination with alumina.	Alumina.	Water.	Formula for the plastic portion alone.
1	9.76	1.33	—	trace	10.98	31.09	34.65	12.17	$Al_2O_3, SiO_3 + 2$ aq.
2	8.96	1.80	—	"	2.67	37.24	36.37	12.94	ditto
3	24.87	1.56	—	"	7.79	25.14	29.88	10.73	ditto
4	4.30	1.55	—	"	10.19	34.07	36.81	12.74	ditto
5	48.00	—	—	1.23	6.62	17.32	21.14	7.42	ditto
6	4.50	2.85	traces	0.56	9.71	36.77	37.38	12 83	ditto
7	26.42	1.13	—	trace	7.13	25.35	29.45	10.50	ditto
8	34.44	1.57	—	"	7.17	21.44	25.75	9.60	ditto
9	18.00	0.69	—	"	1.76	34.22	34.12	11.01	ditto
10	12.33	0.60	trace soda	"	9.10	31.68	34.16	12.10	ditto
11	43.84	no ko.	—	"	4.44	21.66	22.50	7.55	ditto
12	0.74	0.95	—	"	2.40	41.72	40.61	13.56	ditto
13	13.36	0.54	0.93	"	7.04	31.53	34.99	12.52	ditto
14	0.11	—	—	"	3.72	36.90	43.93	14.62	ditto
15	5.64	0.88	—	trace	6.48	36.77	37.38	12 83	ditto
16	34.99	—	—	"	9.39	20.34	25.59	8.94	ditto
17	33.52	0.71	—	trace	1.82	27.60	25.00	9.80	$4\ Al_2O_3, 5\ SiO_3 + 8$ aq.
18	9.67	1.39	—	"	2.43	39.88	34.51	12.09	$3\ Al_2O_3, 4\ SiO_3 + 6$ aq.
19	28.63	1.13	—	"	4.95	29.03	26.66	9.55	ditto
20	8.14	3.21	—	"	1.16	43.87	32.24	11.36	$2\ Al_2O_3, 3\ SiO_3 + 4$ aq.
21	19.65	0.60	trace soda	"	1.27	45.36	24.06	8.74	$Al_2O_3, 2\ SiO_3 + 2$ aq.
22	27.50	3.98	—	1.31	0.67	38.48	20.92	7.26	ditto
23	50.40	1.83	—	0.56	1.00	25.67	15.17	5.22	ditto
24	22.81	1.14	0.72	trace	12.23	20 46	35.01	12.12	$3\ Al_2O_3, 2\ SiO_3 + 6$ aq.
25	—	—	0.50	"	14.37*	28.75	33.00	23.00	$Al_2O_3, SiO_3 + 4$ aq.
26	42.00	1.24	—	0.48	9.07	18.15	20.00	9.03	$2\ Al_2O_3, 2\ SiO_3 +$ aq.
27	24.64	6.33	—	trace	—	37.07	25.28	6.64	$2\ Al_2O_3, 3\ SiO_3 + 2$ aq.
28	68.18	3.08(ko.)	—	0.43	—	13.72	9.80	2.62	$2\ Al_3O_3, 3\ SiO_3 + 3$ aq.
29	24.64	4.32	—	3.37	5.09	30.52	22.33	9.70	$2\ Al_2O_3, 3\ SiO_3 + 5$ aq.
30	5.53	1.80	—	trace	?	45.07	38.15	9.69	$2\ Al_2O_3, 3\ SiO_3 + 3$ aq.
31	—	—	0.68	"	7.32	21.98	47 83	22.23	$4\ Al_2O_3, 2\ SiO_3 + 11$ aq.

THE LOCALITIES OF THESE CLAYS ARE:

1. St. Yrieux, near Limoges.
2. Clos de Madame (D. Allier).
3. Chabrol (D. Puy de Dome).
4. Plympton (Devonshire).
5. Bourgmanero (Piedmont).
6. Rama, near Passau.
7. Auerbach, near Passau.
8. Diendorf " "
9. Aue, near Schneeberg.
10. Seidlitz, near Meissen.
11. Morl, near Halle.
12. Münchshof, near Carlsbad.
13. Bornholm Island (Sweden).
14. Oporto, in Portugal.
15. Sargadelos, in Galicia.
16. Newcastle (Delaware).
17. Kaschna, near Meissen.
18. Pieux, near Cherbourg.
19. Zetlitz, near Carlsbad.
20. Chiesi (Elba).
21. Breage, Cornwall.
22. Schletta, near Meissen.
23. Prinzdorf, in Hungary.
24. Wilmington (Delaware).
25. Louhossoa, near Bayonne.
26. Mercus (Dep. Arriège).
27. Tretto, near Schio.
28. China.
29. Meude (Dep Lozère).
30. Sosa. near Johanngeorgenstadt.
31. Risanski, in Russia.

* In these analyses the quantity of silica which can be separated by potash is not stated by the analysts; it has, therefore, been calculated from the formulæ.

When the above formulæ for the composition of the porcelain-earths are arranged in the manner exhibited in the table below, so that the amount of alumina shall be the same in all, the general relations in which the different constituents stand towards each other will become more apparent. We thus obtain:

No. 1 to 16	= 24	eqs.	silica+	24	eqs.	alumina+	48	eqs.	water.
No. 17.	= 30	"	"	+ 24	"	"	+ 48	"	"
No. 18+19.	= 32	"	"	+ 24	"	"	+ 48	"	"
No. 20.	= 36	"	"	+ 24	"	"	+ 48	"	"
No. 21, 22, 23.	= 48	"	"	+ 24	"	"	+ 48	"	"
No. 24.	= 16	"	"	+ 24	"	"	+ 48	"	"
No. 25.	= 24	"	"	+ 24	"	"	+ 96	"	"
No. 26.	= 24	"	"	+ 24	"	"	+ 12	"	"
No. 29.	= 36	"	"	+ 24	"	"	+ 60	"	"
No. 27.	= 36	"	"	+ 24	"	"	+ 24	"	"
No. 28 to 30.	= 36	"	"	+ 24	"	"	+ 36	"	"
No. 31.	= 12	"	"	+ 24	"	"	+ 66	"	"

whence it will be seen, that 18 varieties really consist of Al_2O_3, SiO_3, (*i. e.* of as many eqs. of silica as of alumina), as was indicated in the general formula for the porcelain-earths above, and that the remainder contain an excess of silica, which is either in some other form of combination, or, as is more probable, is an accidental ingredient, and due to the inefficient action of the caustic potash upon the porcelain earth. Supposing the former assumption to be the true one, the formation of the porcelain-earths can only vary with the silicate of potash, which is simultaneously produced from the felspar, and the composition of which must approach more or less near to that indicated by the formula $KaO,3SiO_3$. If we deduct from:

2 equivs. of felspar $= 2Al_2O_3+2KO+8SiO_3$, the constituents of the porcelain-earths, No. 27 to 30:

$= 2Al_2O_3+3SiO_3(=24Al_2O_3+36SiO_3)$, there will remain a silicate of potash:

$$= 2KO,5SiO_3(=\overline{KO,2\tfrac{1}{2}SiO_3}).$$

The number of the equivs. of silica is less than that of the equivs. of alumina in two instances only (Nos. 24 and 31); and when these are compared with felspar in the same manner as the preceding, it will then be found, that the silicates of potash which accompany them will be expressed, in the first by the formula $3KO,10SiO_3$, and in the second by $2KO,7SiO_3$.

Lastly, it is singular that in 24 instances the water should be in the same proportion to the alumina, as 2 equivs. to 1 equiv.; in the others, the water is in excess, with the exception of one only (No. 26), where it is less.

The older analysts (Fuchs, Forchhammer, Berthier), who did not endeavor, like Brogniart and Malaguti, to separate the soluble silica by caustic potash, were led to the following formula for the greater

number of the porcelain-earths; $3Al_2O_3,4SiO_3,6aq.$, which includes an equivalent of silica more than those noticed above. The same experimenters have also instituted comparative analyses between the earths and the felspathic rocks, in cases where the former were indubitably derived from the latter, by which means the general theoretical view deduced from the above has been verified for a particular case. They found, for instance, in 100 parts of the felspar from Halle:

	Silica.		Alumina.		Potash.		Magnesia.		Lime.
=	62.76	+	19.20	+	14.90	+	0.18	+	0.46;

if from this we deduct:

$KaO,3SiO_3$ =	43.95	+			14.90, there will remain	
=	18.81	+	19.20		0.18 + 0.46	

for the porcelain-earth which yielded, on analysis:

+ 18.48 + 19.20 + small quantities of lime and magnesia.

When in like manner from 100 parts of the felspar of Sargadelos,

	Silica.		Alumina.		Potash.		Magnesia.		Lime.
=	62.00	+	19.48	+	15.72	+	0.12	+	0.35;

we deduct the corresponding porcelain-earths:

	= 19.16	+ 19.48		+	0.45
there remains	42.84		+ 15.72		

the amounts of oxygen in which are

= 22.13, and 2.58, and which is therefore a silicate with $\frac{22.13}{3 + 2.58} = 2.86$ eqs. of silica to 1 eq. of potash, or $KO,3SiO_3$, as is required by the foregoing theoretical considerations. As additional proof of the production of porcelain-earth from felspar, the fact observed by Berthier may be adduced, who found the remains of a rock in the porcelain-earth from Limoges to consist of 4 eqs. silica, 1 eq. alumina, and 1 eq. of potash, such being the precise composition of potash-felspar.

The pure aluminous constituent does not dissolve in dilute muriatic or nitric acid; on boiling the clay for a length of time, however, with caustic potash, a double silicate of alumina and potash is formed, which dissolves with facility in proportion to the quantity of potash that has been employed. The same phenomena occur when the two substances are caused to act upon each other by fusion; the fused mass then yields to water both alumina and silica in proportion to the quantity of potash employed. This solubility, or rather property of being decomposed by potash and acid, still obtains when the silicate of alumina has been so far heated as to part with its water, but is totally destroyed by a red heat.

The most prominent physical properties of clay are, its plasticity and behavior when exposed to heat. By simple drying, therefore,

at a temperature far below a red heat, its particles collapse, the primary pores become contracted, and a very much more dense mass is obtained, which becomes so hard that it will no longer take impressions, although it is still sufficiently soft to be easily cut with a knife, and when treated with water, is again converted into clay with the ordinary properties. Exposed to the most intense heat that can be artificially produced, clay refuses to become liquid, and acquires at most a slight degree of flexibility. Its particles then cohere so strongly together, that the burnt mass is hard and sonorous, but still porous enough to absorb water with avidity, although it no longer falls to pieces, but retains its connected form. While an increase of temperature brings the pores continually more close together, and the burnt clay increases (for the same volume) in density (and in hardness), yet it is very remarkable that this is not the case with the mass itself (apart from the pores). Laurent has proved this by weighing porcelain-clay pulverized after it had been dried or burnt. With porcelain-clay which had been exposed to a

Temperature of	100° C.	150° C.	300° C.	Cherry red heat.	Lively red heat.	White heat, low.	White heat, intense.
The cubic inch weighed (in powder in grammes - -	58.58	39.52	40.61	42.17	41.24	39.05	38.74

whence it is obvious how the density of the mass itself attains its maximum at an incipient red heat, and is reduced at a white heat to the same state which it had acquired at 100° C. In the commencement the clay loses water, and, indeed, after having been dried at 150° C., as much as 8½ per cent. This weight then remains unalterable, but other changes occur at a red heat: the particles of clay are augmented in volume, and possess consequently a lesser density. At the same time, however, they approach more closely together, the interstitial spaces are diminished, and an increase of density of the whole burnt clay as a mass is the consequence, which is practically observed by a diminution of surface, and is called the *shrinking* of the clay.

It will easily be conceived that the nature of the clay must be very much modified in these important particulars by an admixture of foreign matters possessing other properties. These foreign matters may either be constituted of undecomposed detritus of the rocks from which the clay itself derives its origin, or of others which do not belong to the class of substances which yield clay by decomposition. We find an instance of this in the remains of felspar and free silicic acid in the porcelain-clays; a similar relation has been pointed out by Forchhammer in a yellow clay extensively diffused in Denmark, which clearly exhibits the granitic source of the clay:

The granite contained: felspar, quartz, mica, magnetic iron and oxide of titanium, with compounds of cerium.
" clay " : kaolin, sand, mica, oxide of iron and titanium, and compounds of cerium.

In this case the clay was derived from the felspar; the quartz remained as sand, the mica was unaltered, (but in the form of a fine powder, that cannot be separated by suspension in water,)* and the magnetic iron had been converted into oxide of iron, which was mixed with compounds of titanium and cerium in the clay. The same relations are generally met with in clay which has not been removed from the place of its production. On the other hand, the clay may have been carried away by floods and rains from its original site, which naturally remove with the clay all such matters as happen to lie in their course and are capable of suspension in water. When these waters attain a degree of rest in the valleys and low situations, all the finely-divided matters which have been held in suspension, are deposited with the clay.

The character of these foreign admixtures causes great variation in the nature of the different clays, (particularly for practical purposes,) and gives rise to the various denominations by which they are known. The ingredients which most affect the character of the clay are: *Sand* (quartz, in grain or powder; particles of undecomposed minerals), *Iron*, *Lime*, and *Magnesia*. The plasticity of clay diminishes with the amount of any one of these substances which it contains, as they are not plastic. This property is affected in the most marked manner by sand, somewhat less by lime, and very little by oxide of iron. Clay containing the former is said to be *poor*, in contradistinction to *fat* clay. It is not uncommon to meet with clay that has not only been contaminated, but has really been freed from the coarser particles of sand by a natural process of suspension and subsidence caused by floods, and when this has been the case, the clay possesses a much greater degree of plasticity without losing its persistence in the fire, or its color. When clay contains iron or lime, the action of heat upon it is very different; the silica, alumina, lime and iron then form together a mixture similar to that employed in the manufacture of bottle-glass, which melts in the fire with more or less ease, according as it contains much or little of the two latter ingredients. Magnesia exerts less influence upon the character of the clay; the more quartz and silica enter into the composition of the clay, the less easy will it be of fusion, and an excess of iron or lime can be corrected by a large quantity of this ingredient. The fixed or *fire-proof* clays are thus distinguished from the *fusible* clays; but the appellation of *fire-proof* must only be used in a qualified sense, depending upon the degree of heat that is employed. In burning fusible clay, care must consequently be taken not to exceed the proper degree of heat, that the clay may not be melted. These varieties can never be burnt at such high temperatures as the fire-proof clays. Clays containing iron are either yellow or red after burning, according as they contain little or much of the metallic oxide. The color of the fresh clay generally betrays the presence of iron (when in the state of oxide). Many kinds of clay (particularly such as have been deposited by water), are permeated by an organic

* The same observation as respects the mica has been made with the Devonshire clays in England.

substance (possibly originating with infusoria) which gives them a blue, bluish-gray or black color. These coloring matters are of no practical importance, as, exposed to the influence of fire, the clay becomes white. The same applies to clay which comes to the surface, and is penetrated by the roots, &c., of vegetables. Large pieces of root or wood are objectionable, as they leave a space after the clay has been subjected to heat, and often cause it to crack by evolving gases and vapors in the furnace.

Brogniart has very appropriately classified the varieties of clay, with a technical object in view, into: *fire-proof*, *fusible*, *calcareous* and *ferruginous*. The calcareous are those which effervesce considerably with acids, from containing a large proportion of earthy carbonates, particularly lime; the ochry or ferruginous clays are such as contain a large quantity of peroxide of iron, and possess a red-brown color. These terms are taken from the preponderating property of the clays, and do not exclude entirely any of the others. To the fire-proof clays belong:

1. *Kaolin*, or *Porcelain-earth*.—This is an earthy, pure white, grayish or milk-white substance, easily pulverized, and intermixed with particles of quartz and felspar. It occurs on granitic soils, rich in felspar, but containing little mica; on porphyry, and the more recent formations containing felspar. It is the most important material for the production of porcelain. The chief localities of this substance are Seidlitz, near Meissen; Morl, near Halle; Obernzell and Diendorff, near Passau; St. Yrieux, near Limoges (Dep. Nièvre); St. Austle, in Cornwall; China and Japan. Kaolin burns perfectly white. As the associated particles of felspar (the residue) in the kaolin, which also enter into the composition of the porcelain, were omitted in the analyses (of the aluminous portion) stated above, some analyses of the entire material are given below:

	100 parts contain				
Kaolin from According to	St. Yrieux. Berthier.	Aue,* Kühn.	Passau, Fuchs.	Halle, Bley.	St. Tropez.
Silica	47.09	47.64	43.65	39.62	55.8
Alumina	36.41	35.97	35.93	45.00	26.0
Potash	1.56	—	—	—	8.2
Magnesia	2.94	—	—	3 32	0.5
Lime	—	1.57	0.88	0.07	—
Oxide of iron	—	—	1.00	—	1.8
Oxide of manganese	—	—	—	0.19	
Water	12.00	13.18	18.50	10.00	7.2

Besides the real porcelain-earth, a kind of granite containing semi-decomposed felspar, is employed and brought into commerce in England, where it occurs at Tregoning Hill, near Hellstone.

The finest clay (termed *china-clay*) used in Britain is obtained from Cornwall, where it is prepared artificially by running a stream of water over decomposed granite, which carries with it the finer parti-

cles of felspar, and is then received into catchpools or ponds, and there the latter is allowed to subside. The water is then run off, leaving a fine sediment, which is removed and exposed to the atmosphere for four or five months, when it is ready for exportation. This clay, previously dried at 212°, was found to consist of

	I.	II.	III.*
Silica	46.32	46.29	35.65
Alumina	39.74	40.09	32.50
Protoxide of iron .	.27	.27	1.65
Lime	.36	.50	traces
Magnesia	.44	—	traces
Water and some alkali	12.67	12.67	30.05
	99.80	99.82	99.85

Richardson.

Another substance, very nearly allied to kaolin, and which occurs in large quantities at Houscha, near Bayonne, and is often offered to the manufacturers of porcelain, has been shown by Berthier to be halloisite, mixed with a product of the decomposition of pegmatite. It forms a connected, tolerably soft, and easily pulverized mass, is of a dull white color and opaque, affording no dough with water, and is consequently not plastic. Berthier found in it:

Silica . .	43.6 . .	3 equivs.	$=2Al_2O_3,3SiO_3+8$ aq.
Alumina .	32.4 . .	2 "	
Water .	23.0 . .	8 "	
	99.0		

2. *Pipe-clay* (plastic clay) is of different colors, very tough, exceedingly plastic, and becomes white, or sometimes yellow in the fire, from a small quantity of iron. It is used in the manufacture of stone-ware, clay pipes, earthenware, &c., and occurs in very considerable quantities, but not upon the original site of its production. The most generally known localities where it occurs are on the Lower Rhine (Cologne, Coblentz), near Halle; in Devonshire and Stourbridge, in England; and at Dreux and Forges-les-Eaux, in France. The following analyses show that these clays contain but little iron and foreign earths.

* This specimen, analyzed by Richardson, was in the unprepared state.

	Grossalmerode.	Strassburg.	Stourbridge.	Forges-les-Eaux.	Devonshire.	Coteau de Prairie (North America).
	Forchhammer.	Berthier.	Berthier.	Berthier.	Berthier.	Catlin.
Silica - - - - -	15.906	66.7	63·7	52.0	49.6	48.2
Alumina - - - -	11.170	18.2	20.7	27.0	57.4	28.2
Lime - } Magnesia } - - -	3.504	—	—	—	—	2.6
		0.6	—	—	—	6.0
Potash - - - - -	0.786	—	—	—	—	—
Water - - - - -	4.119	12.0	10.0	19.0	11.2	—
Oxide of iron - -	—	1.6	4.5	2.0	—	5.0
Oxide of manganese -	—	—	—	—	—	0.6
Residue - - -	64.030	—	—	—	—	—

Pipe-clay occurs in England as a second layer below the sandy clay, which is used in making tobacco-pipes. This clay is not employed in manufacturing earthenware, owing to its possessing the property of contracting more than sandy clay. It is composed of:

Silica - - - - -	53.66
Alumina - - - - -	32.00
Protoxide of iron - - - -	1.35
Lime - - - - -	.40
Magnesia - - - - -	trace.
Water - - - - -	12.08
	99.49

No clue, however, is given by these analyses to the nature of the aluminous compound, as it is not stated what proportion of the silica is in combination with the alumina, and what proportion is free, and the amount of residue not capable of decomposition by the aid of sulphuric acid is only stated in one instance. Hence the great differences in the relative proportion of the alumina to the silica, which, observing the same order, is as follows: 3 : 1, 4 : 1, 3 : 1, 2 : 1, 1 : 1, and 2 : 1 equivs. Pipe-clay also burns white in the fire.

To the fusible clays belong:

1. Ordinary *potter's-clay* which is used for the production of the common clay-ware. It is more easily disseminated through water than pipe-clay, and is quite as plastic as the latter, but is distinguished by containing a very sensible quantity of iron and some lime. It effervesces consequently with acids although only slightly, and not for any time. The color of the fresh clay is generally red or brown-red, often from the intermixture of various layers it is parti-colored (for instance white and red): this clay is, on the whole, less homogeneous than pipe-clay, encloses a considerable amount of organic remains, fragments of stone and iron pyrites, and varies exceedingly in different localities, being sometimes fat, at others poor. Potter's-clay is always red or yellow after burning, in consequence of the presence of oxide of iron; it fuses more or less easily, according to the quanti-

ties of this ingredient and of lime which it contains, into a dark vitreous slag. There has been found, for instance:

By	In potters' clay from	Silica.	Alumina.	Iron.	Lime.
Aubert	Provins (D. Seine et Marne)	57	37	4	1.7
Berthier	Livernon (Dep. Lot)	60	30	7.6	2.4
Laurent	Helsingborg	61	24	7.5	0.5

The relation of the silica to the alumina in equivs. is, therefore, as 5 : 3, 2 : 1, and 5 : 2.

The more common clays are found in England in layers or strata, lying over each other, each layer possessing some distinctive property, which renders it fitted for a peculiar purpose.

Sandy clay (stiff or ball) is the upper layer of clay, and is used in England by itself for making salt-glazed ware, for which it is well adapted, in consequence of the considerable quantity of silica or sand which it contains. The analysis of this clay yielded:

Silica	66.68
Alumina	26.08
Protoxide of iron	1.26
Lime	.84
Magnesia	trace.
Water	5.14
	100.00

It was previously dried at 212°, and possessed a specific gravity of 2.558.

Blue clay is of a grayish color, and is considered the best layer of clay in the whole series, owing to its burning perfectly white, and approaching the china-clay in character. As analyzed by Mr. John Higgenbotham, it was found to consist of:

Silica	46.38
Alumina	38.04
Protoxide of iron	1.04
Lime	1.20
Magnesia	trace.
Water	13.57
	100.23

This specimen was also previously dried at 212°. Several other varieties of clay are obtained from these fields which are of less value, and need not be enumerated here, as they are similar in appearance to those already noticed.

Red or brown clay, which is very abundant in the neighborhood of Glasgow, is a surface clay, and contains a large quantity of peroxide of iron, which gives it a deep brown color. It is of this clay that common black ware, flower-pots, and red bricks are made: these ves-

sels cannot be exposed to a very high temperature, which would fuse them. The analysis of this clay yielded:

Silica - - - -	49.44
Alumina - - -	34.26
Protoxide of iron - -	7.74
Lime - - -	1.48
Water - - -	1.94
Magnesia - - -	5.14
	100.00

By mixing sandy clay and red clay together, an artificial yellow clay is obtained, which is often employed.

Yellow clay, as analyzed by Mr. John Brown, was found to contain:

Silica - - - -	58.07
Alumina - - -	27.38
Protoxide of iron - -	3.30
Lime - - - -	.50
Water - - -	10.30
Magnesia - - -	trace
	99.55

A variety, technically called *fire*-clay, is also very abundant in England, and occurs both on the surface and several fathoms under ground. It is termed marl, and is used principally in the potteries for making seggars, or vessels for protecting the ware from the flames during burning; and owing to its coarse particles, which cause the body to be very porous, is well adapted for high temperatures; crucibles, or large pots for glass works, in which the glass is fused, are also made from fire-clay, as well as bricks known under the name of fire-bricks. This clay has been analyzed by Mr. John Brown, who obtained:

Silica - - - -	66.16
Alumina - - -	22.54
Protoxide of iron - -	5.31*
Lime - - -	1.42
Magnesia - - -	trace
Water - - -	3.14
	98.57

2. Under the name of *Fuller's-earth*, a species of fusible clay is known, which, as the name indicates, is used for fulling cloth. It is distinguished from potter's-clay by its slight degree of plasticity, and

* The amount of iron is large in this clay, and would tend to make it easily fusible. Compare page 35.

this is probably due to the magnesia* which it contains, but it is quite as easily formed into an equally soft paste with water. Its color passes from yellow into bluish-green. This clay is said to be a product of the decomposition of diorite and dioritic slate.†

Fuller's earth has a specific gravity of 1.82 to 2.19; it melts at a high temperature into a brown slag. Its constituents are:

Silica	53.0	46.30
Alumina	10.0	25.10
Peroxide of iron	9.75	9.40
Magnesia	1.25	1.15
Lime	0.5	—
Water	24.0	18.50
And a trace of potash	—	—
	98.50	100.45 Richardson.

The cleansing action of this clay upon woollen stuffs, depends upon the power of its alumina for absorbing greasy matters. It should be neither tenacious nor sandy; for in the first case it would not be easily diffused through water, and in the second it would abrade the cloth too much. Fuller's-earth is found in several counties of England; but in greatest abundance in Bedfordshire, Hampshire and Surrey, (near Nutfield, Ryegate, &c.)

The most remarkable among the calcareous clays, are:

1. *The marls.*—This denomination applies to all those deposits which contain at once clay and carbonate of lime, the latter being in considerable quantity. These are mechanical mixtures, and comprise all the intermediate formations between the limestones and the clays; they are consequently of almost every shade of character which is possible to be produced by variable quantities of the two characteristic ingredients. Those in which the lime preponderates, are called *calcareous marls*, the others in which alumina is most abundant, *aluminous marls*. The marls in general are of special importance as affording the most fruitful soil for agriculture. The aluminous marls in particular, are used for the manufacture of several kinds of pottery, for instance, earthenware (fayence); they effervesce violently with acids, and occur chiefly in very extensive stratified layers, consisting of a massive but soft and pulverulent substance, which presents an uneven, conchoidal fracture, and a gray color passing into brown. The mass falls easily in water, and possesses but little plasticity. Aluminous marl is not uniform throughout, but frequently encloses hard, calcareous or silicious nodules; it easily falls to pieces in the air, forming earthy marl; it is reckoned amongst the most extensively diffused varieties of clay. The following analyses exhibit clearly the relation of its constituents:

* The analysis below hardly warrants the assumption that magnesia can interfere with the plasticity of the clay.

† A rock consisting of albite and hornblende.

Locality.	Silica.	Alumina.	Ox. of iron.	Carbonate of lime.	Carbonate of magnesia.	Alkali.	Analyst.
Abydos - - -	52.00	16.17	6.15	13.97	trace	trace	Salvetat.
Bonnefonds - - -	40.00	13.21	2.04	34.12	0.15	"	"
Belleville - - -	46.03	17.28	5.70	27.64	—	—	Buisson.
Chambray - - -	49.50	29.00	3.00	18.00	0.50	trace	Laurent.
Savone - - -	37.00	11.00	6.50	55.00	—	—	Buisson.
Viroflay - - -	39.00	18.00	1.00	40.00	—	trace	Lecoq.
Villom - - -	30.00	20.00	2.00	46.00	—	"	"

A small portion of the lime in the marl is generally in combination with silica.

2. *Loam.*—This is the most common and least pure variety of clay, belonging to the more recent alluvial formations; it is less uniform than any of the foregoing varieties; it encloses sand, gravel, stones, wood, roots and all kinds of vegetable remains. Its color is yellow (spotted and veiny) from hydrated oxide of iron; it also contains lime, although in less quantity than the marl, and is soft and easily reduced to powder. Loam absorbs water with avidity, and forms with it a soft paste, which, however, is much less plastic and fat than that from pipe- or potter's-clay. It occurs almost everywhere, and is the universal material for brick-making.

Amongst the ferruginous clays are:

Reddle, bole, and *ochre.* The two former owe their red color to oxide of iron, the latter derives its yellow color from the hydrate of the same oxide. These varieties are used as pigments, but not for the same purposes as the other clays. The amount of iron which they contain is sometimes so considerable as to warrant their being classed with the ores of that metal.

Varieties and classification of clay-wares.—The production of earthenware from the different kinds of clay, consists in producing the proper form with the aid of the plasticity of the clay, and then modifying the formed vessels, &c., in such a manner by heat, that they become no longer kneadable or flexible, but of a stony consistence, and permanently retain their form. The quality of this earthenware must vary obviously very considerably, according to the nature of the clay, to the processes of purification, &c., to which it has been submitted, to the degree of heat of the furnace, and lastly, according as it has been worked up with other materials or not. The differences which thus arise are partly recognized by the color, the texture, fracture, hardness and solidity, and partly by the sound produced on tapping, partly by the transparency and chemical constitution. Thus many clay-wares have the appearance of being composed of heterogeneous clays imperfectly mixed with each other, and which often contain foreign constituents, as stones, &c. (*bricks, tiles*). Many other kinds, which are, however, of a more homogeneous character, resemble these in the porous nature of the mass, which is wanting in solidity, is easily scratched, soft, of an earthy fracture, perfectly opaque, and

very little sonorous: all ordinary pottery belongs to this class (both ancient and modern) and earthenware.

In contradistinction to these, there are other wares, in which the mass has lost its porosity and the properties connected with it, by the intensity of the heat in the kiln, which combine a dense structure with considerable hardness, produce a clear sound when struck, and are somewhat translucent, with a fracture indicating an incipient fusion, such as *stone-ware. Porcelain* exhibits the same properties, but from other reasons; a fusible substance or *flux* being in this case mixed with the clay. To counteract the porosity of the burnt clay-wares, or to correct the roughness of surface in the non-porous vessels, they are frequently covered with a vitreous coating or *glaze*, which is at different times an enamel, (comp. p. 133), or is transparent; at other times contains lead, is easily fusible and soft; or, again, contains no lead, is earthy, refractory and hard. This glaze is laid on in thinner or thicker coats according to circumstances. Hence, and in the total absence of glaze (antique vessels, chimney-pots, flower-pots, crucibles, bricks, architectural ornaments), new sources of difference arise, and to these we are indebted for the views upon which the following classification of the clay-wares is based.

A. Mass uniformly fluxed, dense, cannot be scratched with the knife, finely granular, *translucent*, very sonorous, white, and uniform.

1.) *Porcelain:*
- *a.*) *Tender porcelain* (*ironstone china*). Mass easily fusible.
  - α.) *English.* Flux, bone-ashes; glaze containing lead and borax.
  - β.) *French.* A vitreous mass, containing no clay, with a lead glaze of harder consistence.
- *b.*) *Real porcelain.* Mass difficult of fusion; Flux, a refractory glass composed of silicate of alumina and potash; glaze of a similar nature, often containg lime.

B. Mass dense, cannot be scratched with the knife, sonorous, finely granular, uniform, exhibiting incipient fusion, scarcely translucent, or only on the edges, white or colored.

2.) *Stoneware:*
- *a.*) *Common stoneware.* Mass of a reddish-gray, or bluish colour; generally without glaze, or a salt glaze only.
- *b.*) *Firestone ware.* Mass generally white, when it contains a flux and has a lead glaze; artificially colored also, without glaze; sometimes lacquered.

C. Mass earthy, porous, pretty hard, opaque, texture open; little sonorous.

3.) *Earthenware* (*Fayence*):
- *a.*) *Fine earthenware.* Mass white, hard and sonorous; glaze of crystal, soft, containing lead.

b.) *Common earthenware.* Mass finely granular, uniform, more or less colored (yellow); glaze, a soft, white or colored enamel.

D. Mass earthy, porous, opaque, very soft, homogeneous texture very open, very porous, always colored.

4.) *Ordinary pottery;* partly glazed and partly not glazed; the glaze may contain lead, or not, but is always easy of fusion, and transparent.

E. Mass (more or less) not uniform, always colored, very soft, porous and open, little sonorous, opaque.

5.) *Bricks, tiles, ornaments,* sometimes glazed; Mass fusible at a high temperature.

6.) *Fire-proof stones, crucibles;* Mass difficultly fusible or infusible, not glazed.

1. OF PORCELAIN.

Historical.—The ware to which the name of porcelain* has been given, was known at a very early period to the Chinese, many centuries before the time of Christ, and was first introduced into Europe from China by the Portuguese. A revival of the porcelain manufacture, which had declined in consequence of the war of invasion, is spoken of as occurring in China 485 years before the Christian era. The produce of China was first imitated in France in a very imperfect manner, about the year 1695, and this ware was known as tender porcelain, or ironstone China. The manufacture of real porcelain was first discovered in Europe by a German of the name of Bötticher, in the year 1703.

Apprenticed to a chemist and druggist in Berlin, who was devoted to the fabrication of gold, Bötticher came into connection with adepts, and at length into possession of a gold tincture, the effects of which brought him such reputation, that Frederick I. of Prussia endeavored to lay hands upon him as a source of the precious metal. He fled to Saxony, where Augustus II. of Poland secured him with the same object in view, and sought to express from him the secret of making gold by imprisonment in the Castle of Königstein; during this time, constant correspondence was kept up between the two governments with reference to his release. As less stringent measures proved unavailing, and the patience of Augustus threatened to break out into anger that might prove dangerous to the prisoner, Bötticher found it necessary to confess his ignorance of the art of gold-making, and endeavored to sooth his oppressor by the communication of an invention relative to the manufacture of a kind of porcelain-ware. This communication did not fall altogether upon barren soil, although it did not

* The term porcellana was probably applied at first to the porcelain-shell only, and given by the Portuguese to this ware from its similarity in appearance to that natural production.

lessen the rigor of his confinement. Bötticher had indeed secretly succeeded, with the assistance of Tschirnhous, who possessed some knowledge of mineralogy, in producing a kind of red stone-ware, very nearly allied to porcelain. After very numerous and laborious exertions, carried on during his imprisonment at Sonnenstein, Bötticher at length, in the year 1709, saw his endeavors crowned with success by the production of true white porcelain. The chief difficulty lay in the discovery of a proper material for its manufacture; this was, however, found in the Kaolin from Aue, near Schneeberg, which was then used as powder in commerce. Bötticher died in the year 1719, at the manufactory of Meissen, which he had founded.

The art spread slowly from Saxony; in 1751 it was introduced at Berlin, 1755 at Nymphenburg, near Munich, 1720 at Vienna, and replaced the manufacture of tender porcelain at Sèvres, near Paris, in the year 1765, after the kaolin had been discovered at St. Yrieux. The first manufactory at St. Petersburg was established in the year 1758, and at Copenhagen in the year 1780.

a.) TENDER PORCELAIN.

French.—The mass of which this species of ware is composed (which has been superseded in France by Bötticher's invention) was formerly a mixture of very different substances, which consisted mainly of silica, with alkaline and earthy salts.

At Sèvres, for instance, the following recipe was observed:

Melted saltpetre - - - -	110
Sea-salt, gray - - - -	36
Alum (generally burnt) - - -	18
Alicant soda - - - -	18
Gypsum from Montmartre - - -	18
Sand from Fontainebleau - - -	300
	500

The first glance at this composition shows at once that the substance resulting from a mixture of such a nature must be altogether excluded from the clay-wares, in consequence of there being no clay in its composition; it is indeed nothing more or less than a glass mixture, and would yield, if submitted to complete fusion, an earthy alkaline glass. The heat, however, is not sufficiently raised to admit of complete vitrification, and the mass is only fritted, this being chiefly effected in the calcining-furnace. The frit, in order to be worked up into paste for forming the vessel, was crushed, lixiviated (in order to remove the soluble salts that had not been decomposed by the silica) and ground with water to the finest powder under mill-stones. At the same time chalk and calcareous marl were ground and brought into the finest state of division by suspension in water, and these, added to the powdered frit, then composed the actual mass for forming

into vessels. The character was more or less vitreous, according to the quantity of chalk and marl employed. At Sèvres, for every

75 parts of frit,
17 " " chalk and
8 " " calcareous marl were used.

These vessels, indeed, contain hardly any clay, and consist chiefly of a difficultly fusible vitreous mass of lime and alumina, which resembles porcelain on account of the imperfect manner in which it has been fused. The mode in which the paste was made into vessels is similar to that followed with other kinds of earthenware. The absence of clay, however, deprives the substance of plasticity, and renders the forming very difficult and expensive, or indeed almost impossible, and there exists no means of binding the particles together. This defect was compensated as much as possible in practice by the admixture of soap and glue, about $\frac{1}{8}$, or gum tragacanth was used; the mass could then be formed in moulds of gypsum, if not upon the potter's lathe.* Another difficulty arose in the firing, from the vitreous nature of the mixture; all the prominent parts of the vessels, if not these themselves, were fused, or became so softened in the heat as to lose their shape. This could only be remedied by supporting them in all possible manners at a great expense of time and trouble. After the first firing, which lasted from 75 to 100 hours, the glaze was applied to the vessels, and this was composed of sand and quartz, litharge, soda, and potash—in fact, was a kind of crystal. A higher degree of transparency, as well as the softer nature of the lead-glaze, distinguish soft from real porcelain. This imitation of real porcelain, by a costly process and the use of a glass-flux, is now no longer practiced, and is only possessed of historical interest.

English.—England is the only country where tender porcelain is still manufactured, in consequence of local reasons being unfavorable to the production of true porcelain.†

English porcelain is, however, fundamentally different from the preceding, and is to be viewed rather as a variety of ordinary porcelain. This will be evident from a glance at the constituents which enter into its composition. The crude materials, viz: are

1. A plastic clay;
2. Porcelain-earth, or china-clay, (kaolin,) which is brought in a washed state from Cornwall, and is of a somewhat calcareous nature.
3. So called *granite*, or *Cornish stone*, a material very much used in the English potteries, and which the manufacturers bring from Cornwall. In that part of the country, the granite hills are intersected by extensive deposits of this stone, in which mica is almost entirely absent, and which consists chiefly of quartz and

* This instrument will be described in detail below, when we shall treat of porcelain.

† The chief reason appears to be the want of a cheap material for constructing durable seggars, the loss of which often amounts in Staffordshire to 15 per cent. or more, at

felspar. This kind of rock, (*pegmatite*,) after exposure to the decomposing action of the weather, is the chief source, but more especially in Cornwall, of the porcelain-earth.* In *Cornish stone*, which is brought with the porcelain-earth into commerce, the decomposition of the felspar has only proceeded so far as to render the stone easily pulverizable, and yet leave it some degree of consistence; it consists of kaolin, undecomposed felspar, and quartz.

4. *Burnt bones.*—The bones, which are partly obtained from native cattle, and are partly imported from America, may be previously used for the extraction of gelatin or glue; or, being submitted to dry distillation, will yield ammoniacal salts, or, lastly, may be used in the form of animal charcoal; but they must be thoroughly calcined before they are applicable to the present purpose, that is, they must have been heated to redness with the free access of air, so as completely to destroy all their organic constituents, and leave only the mineral ash (phosphate of lime, carbonate of lime and a little magnesia) in the form of a perfectly white substance.
5. *Chalk flints.*
6. *Steatite*, or *soap-stone*, is also sometimes used, and is said to diminish the contraction of the wares in the furnace.

The soap-stone from Cornwall contains: magnesia 44, silica 44, alumina 2, iron 7.3, oxide of manganese 1.5, oxide of chromium 1.2, with traces of lime and chlorine.

All these ingredients are ground, suspended in water, and united into the form of paste, in the same manner as will be described below in treating of real porcelain and earthenware. A frit is either then first prepared, of which the mass is made up with other substances, as in the following instance:

FRIT.		MASS.	
Cornish stone	40	Kaolin	33
Flint	28	Plastic clay (blue)	45
Crystalized soda	20	Cornish stone	7½
Borax	7	Flint	3
Oxide of tin	5	Burnt bones	52
		Frit	7
	100		

or the mass is not fritted in part, but mixed all at once, as is the case with table-ware, in the following proportions:

			or
Kaolin	18		11
Plastic clay	50		19
Flint	—	100	21
Calcined bones	29		49
Broken table-ware of the same character	3		
Mould refuse of unfired mass			100.

* Compare page 204.

In all cases, the goods, which are easily formed in consequence of the large proportion of clay in the mass and its high degree of plasticity, are twice fired. The first firing lasts longest, say from 48 to 50 hours, the heat being gradually increased during the whole time. When the trial-pieces show that the heat has been sufficiently raised, the firing is discontinued, the fire and ash-pit doors are closed, and the whole is left to cool during 24 to 30 hours; the glaze is then applied to the vessels, and they are fired a second time, but neither for so long a time, nor at such a high temperature, and in this consists the essential difference between the English and the foreign process, as, abroad, the greatest heat is applied to the glazed vessels and not to the biscuit. The glaze upon table-ware consists of:

Cornish stone	34	which substances are fritted, ground, and then mixed with 10 per cent. of Cornish stone, and 20 per cent. of whitelead.
Chalk	17	
Ground flint	15	
Borax	34	
	100	

The lead is sometimes entirely omitted from the mixture for the glaze, and the proper degree of fluidity is then brought about by an additional quantity of borax. The lead and borax-glaze of this kind of porcelain is soft, but pure and sufficiently brilliant for the ordinary paintings and decorations.

It is worthy of special notice that the celebrated Wedgewood-ware (from the name of the inventor) is composed of a clay composition and a frit, and is classified with more propriety under this kind of porcelain than with stoneware, as is more commonly the case.

Bone is a very important ingredient in English china, and enters largely into its composition. The phosphoric acid of this ingredient diffuses itself at a high temperature through all the materials, and unites them into a translucent enamel, which is less apt to sink and lose its form than the hard china; it may, consequently, be baked in larger kilns, and with less risk of loss to the potter.

Body.—The following are approved mixtures for English china body.

	I.	II.	III.
Bone	46	4	4
China clay	31	—	—
Cornish clay	—	3½	3
Cornish stone	23	2½	2½
Flint	—	—	½

The bone and flint being some times fritted to produce the highest degree of vitrescence, and then mixed up with the other ingredients. A little Dorset clay is sometimes added for large pieces, as dishes, &c., to give more ductility in working and stability in the fire. The beautiful material of the small ornamental figures and statuettes called Parian, and manufactured by Mr. Minton, is said to be a more highly vitrified porcelain taking the highest degree of heat. The firing of

this material must, no doubt, be regulated to a very great nicety, as its peculiar degree of transparency, bearing a great resemblance to marble or ivory, appears to be entirely dependent upon temperature.

The heat of the kiln for busquit porcelain varies according to the composition of the ware, but ranges from 100° to 110° Wedgwood. This pyrometer is, however, never used in the potteries, but the proper temperature is regulated by small trial pieces of the same material as the goods to be fired. The firing lasts from 40 to 50 hours, and the average quantity of coal consumed is from 10 to 12 tons.

Composition of Soft China.—The following are some recent analyses of English china, by Mr. Cowper.

	No. 1.	No. 2.	No. 3.
Silica	39.88	40.60	39 685
Alumina	21.48	24.15	24.650
Lime	10.06	14.22	14.175
Protoxide of iron, Phosphate of lime	26.44	15.32	15.386
Magnesia		.43	.311
Alkali and loss	2.14	5.28	5.792
	100.00	100.00	100.00

English China Glaze.—The glaze employed for English china is harder than that employed for earthenware: the following substances enter into its composition in the following proportions.

Cornish stone	109	These are fritted together with 20 per cent. of white lead and 10 per cent. of flint.
Calcined flint	60	
Carbonate of lime	25	
Cornish clay	10	
Soda	10	
Borax	60	
White lead	30	

The following are also said to be excellent.

Cornish granite	25	Fritted in gloss-oven and then the following mixture is used.	Frit	26
Soda	6		Cornish stone	26
Borax	3		White lead	31
Nitre	1		Flint	7
			Carbonate of lime	7
			Oxide of tin	3

The whiteness is increased by a little oxide of cobalt.

Another glaze for China is given below:

Felspar	38	Fritted together and mixed as follows.	Frit	60
Lynn sand	24		Cornish stone	20
Carbonate of lime	11		White lead	20
Borax	27			

The temperature of the glaze-kiln is about 60° Wedgw., but this also varies with different circumstances in the manufacture. The

time required for burning the glaze is about 17 hours, and the consumption of coal on an average is 6 tons.

Colors.—The colors employed in painting upon English china are prepared from metallic oxides, ground up with fusible glasses or fluxes of various degrees of softness. The flux most generally used is composed of:

Red-lead - - -	6
Borax - - - -	4
Flint - - - -	2

The painted goods are placed in the enamel-kiln, as was the case with hard china, where the fluxed colors melt and attach themselves to the glazed surface producing colored glasses.

Gold is applied to china in the state of an amalgam ground up with turpentine and a metallic flux. Thus, oxide of gold, 1 oz.;* mercury, 14 pennyweights; oxide of bismuth, 1 pennyweight; chloride of silver, 2 pennyweights. The bismuth and silver are melted in the enamel-furnace, and fix the gold to the china in such a manner that it can be subsequently burnished with agate.

Composition of Clays and of Porcelain.—The following analysis of clays and porcelain have been recently published by Mr. Cowper:

TABLE OF THE COMPOSITION OF CLAYS AND PORCELAIN WHEN FREE FROM WATER.

	Silica.	Alumina.	Protoxide of iron.	Lime.	Magnesia.	Phosphate of lime and protoxide of iron.	Alkali and loss.	Specific gravity.
Cornish china-clay	53.16	45.61	.31	.41	.51	—	—	—
" "	53.12	46.00	.31	.57	.51	—	—	—
Sandy clay - -	70.29	27.47	1.33	.90	trace	—	—	2.558
Pipe " - -	61.39	36.61	1 54	.46	—	—	—	—
Blue " - -	53.52	43.89	1.20	1.39	—	—	—	—
Red " - -	52.11	36.19	8.17	1.56	2.04	—	—	—
Fire " - -	69.33	23.62	5.56	1.49	trace	—	—	—
Yellow " - -	65.06	30.68	3.70	.56	—	—	—	—
English china-ware -								
No. 1. - -	39.88	21.48	—	10.06	—	26.44	2.14	—
No. 2. - -	40.60	24.15	—	14.22	.43	15.32	5.28	—
No. 3. - -	39.68	24.65	—	14 18	.31	15.39	5.79	—
Berlin ware -	72.96	24.78	—	1.04	trace	—	1.22	2.419
Superior china ware	71.04	22.46	—	3.82	—	—	2.68	2.314
Inferior "	68.96	29.24	—	1.60	—	—	—	2.314
Common English white ware - -	68.55	29.13	—	1.24	—	—	—	2.360

* Prepared by pouring melted gold into nitric acid.

b. TRUE PORCELAIN.

Nature of the Mass.—The clay-wares which are known under this name, and which are manufactured in China and in all European countries (with the exception of England), are composed of two essentially different constituents, the one of which is an infusible, plastic, white clay, called *kaolin*,* or China-clay; the other, an infusible, not plastic material, the so-called *flux*. The latter is almost universally composed of felspar, with the addition of quartz, chalk, and gypsum.

Kaolin alone, would afford a porous, opaque body; the flux, however, softens in the heat of the porcelain-kiln, and penetrates as a vitreous matter the whole body of the clay, completely filling all the pores and covering all the surface, it binds the whole together into a dense impenetrable mass. The translucency of this materal is, therefore, due to the clay body being saturated, as it were, with a mass of glass, as transparent paper is permeated with oil. Under the microscope, the two ingredients can be clearly distinguished separate from each other, and the milky mass appears as a transparent ground mixed with an opaque ingredient, which, according to Ehrenberg's observations, consists of articulated threads (*i. e.*, composed of globules arranged in a linear direction, one on the other) or little rods, which are interwoven, and cross each other in all directions.

According to the microscopic observations of Oschatz and Wächter, the porcelain mass consists of a vitreous matrix which is intersected in all directions by innumerable crystaline needles of the most minute dimensions, and its want of transparency is due to the reflection and refraction of the light from the surfaces of these crystals.

The Glaze.—The glaze is equally characteristic, and is always composed of felspar, sometimes mixed with a little gypsum, but never with lead or tin. The glaze is consequently of the same nature as the flux, and being brought into the most intimate connection with the flux and the mass, the most essential property of porcelain is thus secured, *i. e.*, the glaze cannot be separated or peeled off from the substance of the vessels by outward shocks or sudden changes of temperature. If the property of expansion by heat of the glaze were materially less than that of the mass, the former would not be able to expand with the latter, and at high temperatures the glaze would no longer cover the entire surface of the vessels, but would split in various parts, like a garment that is too tight. Of all kinds of clay-ware, porcelain is least liable to exhibit that kind of fine net-work on its surface which is produced in the other kinds by the splitting or crazing of the glaze. The glaze being free from lead, and consequently very hard, enables it also to resist the effect of the knife and fork in cutting, &c.

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* The word Kaolin is the original Chinese Kao-lin, and has been gradually adopted in all European languages.

The nature of porcelain clearly shows that kaolin and felspar are its principal ingredients, and the ware might be appropriately called kaolin-ware. The mass for porcelain vessels is composed as follows:—

TRUE OR HARD PORCELAIN.

COMPOSITION OF THE MASS.

In Berlin.				In Vienna (1812).	
For domestic use, plates, dishes, &c.		For ornamental purposes.			
Kaolin from Morl	76	Kaolin from Morl	25	Kaolin from Auerbach	72
Felspar	24	" Beidersee	50	Felspar	12
		Felspar	15	Quartz	12
		Pure sand	10	Gypsum	4

In Meissen (Saxony) (commonly called Dresden porcelain.)				In Nymphenburg, near Munich.		
For domestic purposes.		For ornamental purposes.			For low temperatures.	For high temperatures.
Kaolin from Aue	18	Kaolin from Seilitz	37	Kaolin from Passau	62.5	65
Sosa	18	Quartz	37	Quartz	19	21
Seilitz	36	Lime from Pirna	17½	Sand, separated by water from kaolin	6	4
Felspar	26	Broken porcelain	8½	Gypsum	5	5
Broken biscuit porcelain	2			Broken porcelain	7.5	5

In Sèvres, near Paris.		In St. Petersburg.		In Copenhagen.	
For vessels (1843) (compare p. 229.)		For table-ware.			
Kaolin from St. Yrieux	48	Kaolin from Risansky	50	Kaolin from Bornholm	40
Sand, separated from above (containing felspar.)	48	Felspar, Finland	25	Quartz from Arendal	33
Chalk	4	Quartz	25	Felspar	27

Crude materials. Kaolin. Locality.—The kaolin from St. Yrieux-la-perche, near Limoges, occurs below the gneiss. This, as well as the diorite below it, is interrupted and intersected by masses of pegmatite, occurring sometimes in massive deposits, at others in veins. The decomposing action of the weather has gradually converted the gneiss into a red, and the diorite into a blackish-gray mass, resembling kaolin, but which cannot be used, on account of its color. The pegmatite, on the contrary, wherever it is thoroughly decomposed and contains but little quartz, consisting chiefly of felspar, has furnished a *clay-like kaolin* in contradistinction to *stony kaolin*, which contains a quantity of granular quartz, and portions of undecomposed felspar

as sand. Besides these two varieties, there is another distinguished as *sandy kaolin*, in which the two latter constituents preponderate, so as to make the kaolin appear poor.

At Aue, near Schneeberg, in the Saxon Erzgebirge, the source of the kaolin is a rounded mass of granite, very much decomposed on the surface, and entirely surrounded by a deposit of kaolin as with a cap. Then follows a thin stratum of granite, very much decomposed, upon which is found a second deposit of kaolin, of the same nature as the preceding. The whole is overlaid by a kind of gneiss, intersected with numerous veins of quartz and bloodstone.

At Halle (Morl) the kaolin occurs six feet below the surface, not upon granite, but on porphyry.

At Sosa, in the neighborhood of Johanngeorgenstadt, an extensive vein of quartz breaks through the granite to the surface, almost in a perpendicular direction; the vein of quartz is separated from the granite on both sides by a band of ironstone, and wherever the ironstone comes into contact with the granite, the latter is decomposed to a certain extent, while the felspar is converted into kaolin.

At Passau, the kaolin has been formed under precisely the same circumstances as at Limoges.

Preparation of the materials.—It will be obvious from the state in which it occurs, that the crude kaolin is not in a sufficiently pure form for the purposes of the manufacturer, but is a mixture of real kaolin with undecomposed felspar and particles of quartz, which must be separated or finely ground and mixed, so as to form a uniform substance throughout. The process of washing and suspending in water, which precedes the grinding, is generally undertaken at the porcelain-works, but is in some cases partially effected at the pits. At St. Yrieux, for instance, the siliceous kaolin is separated from a great excess of sand, which is not wanted in the manufacture, before being sent away. The decanted earth, or such as has settled down from suspension in water, and the other crude varieties are then worked at Sèvres, near Paris. The decanting or elutriating apparatus consists of three tubs, placed one above the other. The upper row is used for separating that portion of the crude matter which is not capable of being decanted. The middle separates the coarser and more sandy particles from the finer argillaceous, which deposit in the third row of vats, and are there separated from the water. When the crude kaolin is introduced into the uppermost vat, the lumps are broken up by stirring or kneading by workmen or machinery. In the latter case, an upright shaft furnished with horizontal arms, is generally set in motion. When every part has been thoroughly stirred up with the water, the latter is allowed to run off through a plug-hole, situated a few inches above the bottom of the upper vat, into the one below it; (in Sèvres there are six of these vats.) The stones and coarser particles remain behind, while the decanted liquid contains the fine sandy particles mixed with the real kaolin. After remaining for a short time at rest, the sand completely sinks down to the bottom, and the liquor only carries the argillaceous kaolin with it into the lowest vessel, where it is allowed to

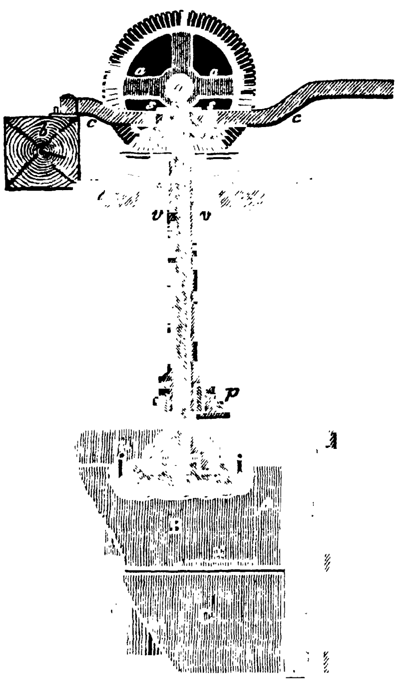
deposit completely before the water is run off from the finely-divided mud. In decanting from the one vat into another, the kaolin *slip** is allowed to pass through hair-sieves, in which the lighter species of impurities, as strips of wood, straw, &c. are easily separated, which would not of themselves fall to the bottom, but float on the surface of the liquid.

This process of decantation yields in Sèvres, a sufficient supply of felspar and quartz in the state of sand, while the stony and argillaceous varieties afford at the same time each their particular kind of sand and crude kaolin.

Chalk, gypsum, broken porcelain.—In Sèvres, the chalk from Bougival is a constant addition to the porcelain-paste; it contains above 95 per cent. of carbonate of lime, but any kind of limestone of equal purity can be substituted for it. At Nymphenburg, the gypsum found at Marquardstein is used for a similar purpose. At the latter place, as in Meissen, fragments of old porcelain are constantly added (like cullet in a glass-mixture;) these injure the plasticity of the paste, however, when allowed to exceed a certain proportion.

As perfect success in the manufacture of good porcelain mainly depends upon the care with which a uniform mixture of the ingredients is effected, it is obviously of the utmost importance that everything by nature of a coarse and massive character, such as felspar (as sand or grains), chalk, gypsum, broken porcelain, &c., must be reduced to the finest state of division. Mills are consequently required which grind these substances to the same state of powder as the kaolin naturally possesses. The woodcut, Fig. 151, represents a mill in vertical section as used at Sèvres.

Fig. 151.



The mills.—Two millstones are fixed in a wooden box, constructed of deals and bound together by hoops; the lower stone C is wedged firmly in the box by means of the cross piece F; the upper stone B, on the contrary, is capable of a rotatory motion. A brass casting *w* is let into the upper surface of the top

* Slip is the term applied in the potteries to any substances in the state of suspension in water.

stone, near the hooks *u u*, in which the shaft *t t* is fixed by means of cavities and arms *x, x*; *v v* is a kind of sheath, supported by the iron beam *p*, which surrounds the shaft *t*. These pass upward through the stay to the cog-wheel *e e*, which matches into the wheel *a*, at right angles to the shaft *t*, and revolving upon a shaft *o*. The iron coupling can be pushed up or down on the shaft *t*, by means of the lever *c*, which forms a ring *s s* in the centre. When the lever is pushed down, the projections *i i* interpose between the spokes of the wheel *e*, and are made to revolve with it; they then communicate motion to the shaft, with which they are firmly connected, and consequently at the same time to the mill-stone *b*. In order to connect the parts *i i i* with the shaft at any time and with ease, or to bring their motion into uniformity with that of the shaft, or put them out of gear, an iron bolt *z* (Fig. 152) may be pushed into a slit, half of which belongs to the shaft *y*, and half to the part in question, *x*. The upper stone B, is not perfectly round, but hewn flat on two sides, and with two grooves opposite each other, *a* and *β*, in order to guide the material better in a downward direction between the two stones. If the pieces of stone are of larger dimensions than those spaces are wide, the former will, of necessity, be excluded from the spot where the grinding is effected. All the materials must, consequently, be brought to a uniform size, under crushing machinery or stampers, before being introduced into the mill.

Fig. 152.

In place of the mills just described, others are frequently employed similar to those which are in use in the English potteries, and of which we shall have occasion to speak hereafter.

Mixture of the mass.—The materials in every case must be ground, and the ground mud must be separated from its coarser particles by decantation, upon the plan pursued with kaolin, so that eventually all the matters employed for the porcelain-paste are in the state of a fine powder, and these must then be mixed in the variable proportions observed in the different manufactories. With this object in view, the matters ought to be mixed in the state prescribed, that is, in a state of perfect dryness, which would be a very tedious and long process. To avoid this, it is usual to ascertain in the first instance, how many pounds of solid residue are contained in a cubic foot of each separate mud (felspar, kaolin, &c.) and then to mix the different ingredients by measure. Of course none of the matters must have completely settled down; but each should form a thickish uniform semi-liquid mass. This method of measuring, although more accurate than that of weighing, by no means secures to the manufacturer the production of the exact mixture that he requires, at least not in those cases where each separate cargo is of so changeable a nature as at Sèvres. The kaolin contains more or less silica and alumina at different times; when, therefore, the mixture is weighed out according to the recipe without further examination, the proper quantities of felspar and kaolin may be obtained, but very incorrect proportions of alumina, silica, potash and lime will be incorporated with

the paste, and upon these its characters chiefly depend. The standing rule observed at Sèvres is, that the best mass for the production of porcelain vessels must be that deduced from the elementary analysis of porcelain of known good quality; or, according to the results of experience, the mixture must consist in 100 parts of

58.0 silica,
34.5 alumina,
4.5 lime, and
3.0 potash,

which numbers are obtained as the mean of analysis. In order to be able to work upon this plan, it is only necessary to make an analysis of each of the materials that are to be mixed together. This will make known the quantity of silica, alumina, lime, and potash which each contains, and afford a safe criterion for calculating how much by weight (and consequently by measure) of each will be required in order to obtain the mean quantity as nearly as possible in the mass. As each cargo of kaolin is chemically a different mixture, the proportions used of it must necessarily be different each time, but the mixture must always contain the same quantity of elementary constituents, as will be evident from the following instances:—

Mixture of 1839,	Contains				Mixture of 1843,	Contains			
Composed of	Silica.	Alumina.	Lime.	Potash.	Composed of	Silica.	Alumina.	Lime.	Potash.
73 Decanted kaolin	38.69	30.66	0.73	1 75	48 Kaolin - -	30	17	0.05	0.96
24 Felspathic sand	19.27	3.40	"	1.27	48 Felspathic sand	28	17	0.53	2 01
6.5 Chalk - -	"	"	3.77	"	7.2 Chalk - -	"	"	4.00	"
	57.96	34.06	4.5	3.02		58	34	4 58	2.97

The practice at Sèvres is not necessarily applicable to other localities; it does not follow that every species of porcelain possessing the same elementary composition as that of Sèvres, should consequently exhibit the same properties; for, although the composition in 100 parts may be identical, still very much depends upon the nature of the proximate ingredients in the mixture.

Drying the paste.—The mixture of the ingredients is effected in large cisterns under constant stirring, and the pasty mass has then to be so far dried that it will form a dough-like kneadable mass. Subsidence does not effect this in the proper manner; in the first place, it requires too much time, and affords, in the second, an opportunity for the heavier particles (the felspar-powder) to separate from the lighter. In short, a disintegration of the mass would be unavoidable, than which, no more serious error could be committed. By ebullition and evaporation, in which case constant currents are kept up in the liquid, a separation of this kind is not likely to occur; but experience has shown, in a remarkable manner, that the mixture for porcelain will not bear such treatment without impairing its plasticity, and becoming, as it is technically termed, "*short.*"

By absorption.—The ordinary mode resorted to in the porcelain manufactories is consequently a drying process by absorption. The paste or mud is drawn off into boxes, the bottoms of which are composed of gypsum, and this attracts the moisture on account of its porosity. The plates of gypsum must, of course, be repeatedly dried. In propitious weather, the drying action of the air is also made subservient to this object.

By presses.—The use of gypsum as a drying agent has been latterly superseded in many places by the plan of pressing, introduced by Honoré, which, although not more economical, has the advantage of communicating a greater degree of plasticity to the paste. The mixture is placed in quantities of ½ or ¼ cwt. in linen bags, and submitted to gradually increased pressure in a screw or lever press. The bags are made from a particular quality of cloth, in which the twisted threads must be of a particular kind as regards density and porosity. The threads must also be carefully freed from filaments, that these may not attach themselves to the paste. It is well to soak the bags, previously to use, in hot linseed oil, which renders them more permeable to water, and more durable.

By atmospheric pressure.—Another contrivance has been carried out in some places, and consists in bringing the paste into a kind of filter, and accelerating the separation of the water (which would go on very slowly of itself) by atmospheric pressure. The apparatus of Talabot consists of iron funnels, terminating in an iron tube. These are covered by a metallic sieve, upon which a thick layer of felt is placed, and upon this the paste is superposed. The exit-pipe is brought into connection with a close chamber, from which the air can be readily exhausted, the weight of the atmosphere then presses from above upon the fluid-level, and causes the water to descend through the paste and felt into the chamber below.

Further preparation and mouldering.—In whatever manner the drying may have been effected, the paste is always obtained of unequal consistence; thus, for instance, the paste from the sacks is much firmer on the outside than in the interior, and this defect is remedied by treading it under the feet, or by beating (slapping). The lumps or balls (it is usual to preserve the paste in this form) are repeatedly and forcibly thrown against a hard stone plate, or are placed between metallic plates with a stamper.

The felspar and lime in the paste are not plastic ingredients; it is, therefore, easy to conceive that this so-called flux, which always amounts to about one-fourth or more of the whole, must very much interfere with its plasticity. Indeed, the degree of plasticity of the paste is very much below that of lumps of pure clay, and the forming or moulding process is consequently more expensive and arduous;* this renders it necessary to neglect no means of increasing the plasticity of the paste. Amongst these may be mentioned the mixing it

* A workman cannot mould more than 60 or 80 plates of porcelain in ten working hours, whilst a man employed with assistants in preparing plates from the more plastic earthenware can finish 600 in the same time.

with fragments from the forming operation, continued treading or kneading, and above all, storing it away in moist layers, in order that a species of decay may be induced.

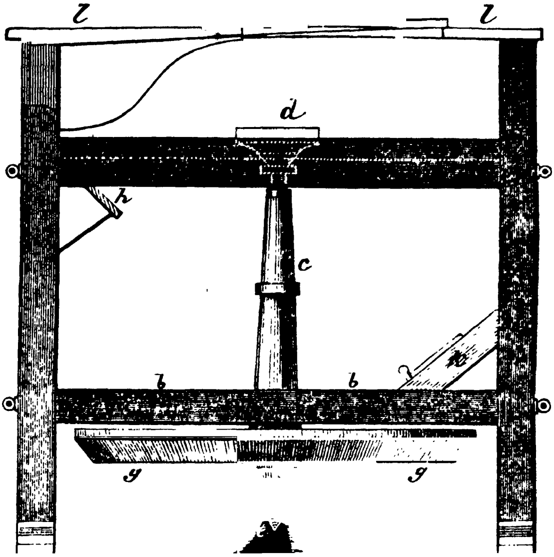
It is never desirable to work paste that has not been stored away in a moist state for a year at least, and it is better when it has mouldered. By this mouldering, we are to understand a curious phenomenon which has not been fully explained, and which occurs when the paste is left to itself in a moist place (not under water), and in lumps of such dimensions as preclude the possibility of its becoming dry in the interior. A fetid smell of rotten eggs is evolved from the mass under these circumstances, and the interior portion becomes of a darker color, passing from gray to black, and which lasts as long as the circumstances remain the same. The black color is produced by the highly carbonaceous product of the decomposition of organic matter, which by a constant absorption of oxygen, as is observed in other cases, reducing the sulphates that may be present (gypsum) to the state of sulphurets, gives rise to the production of sulphuretted hydrogen.

On the outer parts, and wherever the air has access to the blackened portions, the black matter disappears, and the oxygen is converted, under these circumstances, into carbonic acid. It is more difficult to assign a reason for the greater plasticity of the mass that has passed through this process, although all those who are practically acquainted with the subject are so fully convinced of its efficacy, that attempts have been now and then made to facilitate or induce fermentation by the addition of honey, syrup, &c., to the mixture.

Forming or moulding the paste.—The porcelain goods are formed either upon the *potters' lathe or throwing-wheel,* in *moulds* or by *casting.*

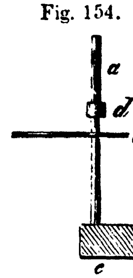
On the lathe or throwing-wheel.—The potters' lathe is one of the oldest machines employed in the arts. Judging from the antique paintings it must have been in use in Egypt 1900 B.C. In the form in which it is now employed in the porcelain manufactories, the disc is placed in the middle of a table *a a*, Fig. 153, with a very massive frame-work as support. The feet of this table are bound together by cross bars, *b*, *b*; *l*, *l*, is a narrow leaf of the table. The disc itself consists of the head, the axle, and the wheel. The axle *c* is made of iron, and is fixed in one point of rotation at *e* (a piece of quartz cemented to the floor by plaster of Paris), whilst the other is situated in the brass ring *d*, which is screwed to the slab of the table. To the lower part of the axle a wide, heavy, horizontal wheel, *g*, *g*, is attached. The *former* or *thrower*, who sits upon the stool *h*, supporting himself with his feet against the board *k*, attains a sufficiently stable position by the inclination of the seat and foot-board, to be enabled to rotate the wheel with one foot. By its weight, and because the greatest weight is placed in the circumference, the wheel works as a balancing-wheel, *i. e.*, it renders the motion in the upper part *d* uniform and continuous, which is of essential importance. This upper part consists of a massive block of gypsum, which is spread

Fig. 153.



out into a flat surface; upon this in the operation of forming, a lump of clay is firmly pressed. When the workman now presses slightly with both hands against the mass, which is kept in constant rotation, the latter gradually acquires a round form; if he forces both his thumbs downwards into the centre, a cavity is produced, which is enlarged by removing his thumbs from each other, and is of a bell shape when these are again brought together. If the sides of the half-finished vessel are closely pressed in a slightly upward direction between hands and thumbs, they will be lessened in thickness, and heightened accordingly. It is absolutely necessary to maintain the hands in a smooth state by constantly dipping them into a vessel containing a quantity of water and paste held in suspension, or they would adhere to the piece and destroy the smoothness of its surface. In this manner all vessels of a circular form in section can be produced; if the mouth of the piece is too narrow to admit of the insertion of the hand, as is often the case with a jug, the piece is either made of two halves, or is formed with a sponge fastened to the end of a crooked stick. If the eye is not sufficiently delicate in estimating the height and width of the pieces, a small rule is used, as shown in Fig. 154. This is merely a narrow rule *b*, which can be fixed in any position in a longitudinal slit or rod *a*, by means of the slide, and can be placed perpendicularly above the piece that is being formed.

Fig. 154.



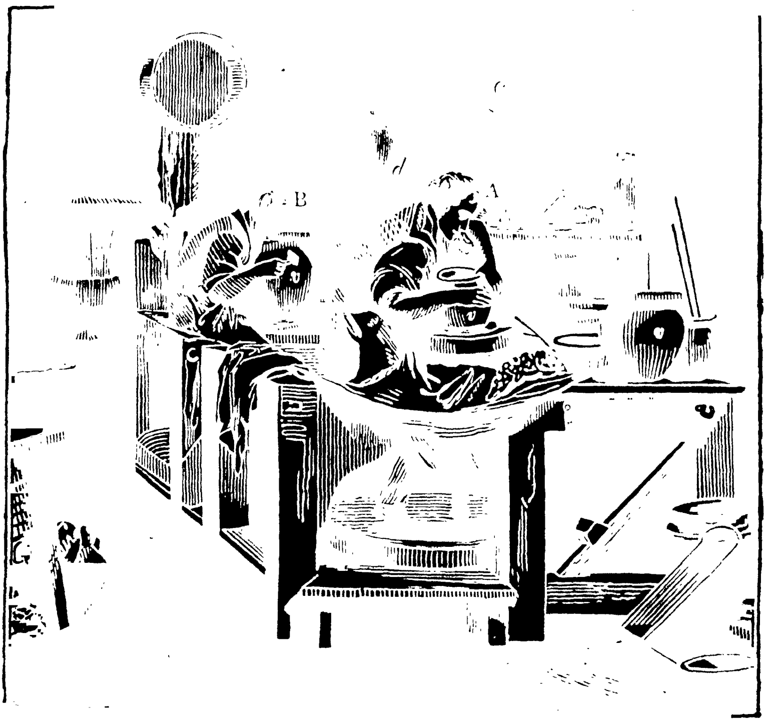
In forming, by means of the lathe, the inequalities of the skin pro-

duce spiral lines on the surface of the pieces, and as neatness and cleanliness are of the greatest importance in the manufacture of porcelain, and, moreover, as the mass is not sufficiently plastic to be worked to the degree of tenuity required by the purchasers, the vessels are formed only in a crude manner upon the throwing-machine, and are brought to the proper dimensions and perfection of form in a subsequent operation.

There are some operations in the manufacture of porcelain which it is impossible to describe, where the movements of the materials and workmen are such that nothing but a personal inspection of the manufacture can convey an adequate idea of their nature. The woodcut, 155, and several of the following, have been executed by the manager of a pottery, and represent the principal operations in the manufacture of porcelain and earthenware so very clearly, that the descriptions preceding them will, by their aid, be rendered much more intelligible to the ordinary reader.

Fig. 155 represents some workmen employed in the operations of

Fig. 155.



throwing and turning. A lump of paste has been brought to the workman A, sufficiently large to form the vase *v*; he has placed it upon a plaster support which covers the top of the axle of the lathe,

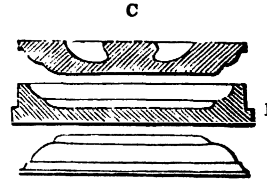
and he is in the act of throwing, working with his foot and hands at the same time. By his side is a kind of skin or apron for catching the slip which is thrown off in the operation. B is employed in the next stage of the process, or in finishing the piece with the iron gauge in his right hand: *c* is a compass or calliper to regulate the degree of thickness, and *d* the model vase, which is the pattern of the one in progress.

Gypsum Moulds.—All objects which are not circular in section, oval, therefore, and other angular shapes, which cannot be turned, are formed in gypsum *moulds*, in which those parts corresponding to the prominent parts on the pieces, are of course sunk, and *vice versâ*. While, on the one hand, the mass to be formed must be so tractable as to be easily introduced by kneading into all the cavities of the mould, it must, on the other hand, be so stiff, on its removal, as not to bend; it must, consequently, acquire consistence, and dry in the mould. This important condition renders it absolutely necessary to employ substances of a porous nature for constructing the moulds, as otherwise the piece would stick and bend on being removed.

Gypsum is, therefore, the only substance (with the exception of burnt clay) that can be used for the moulds. In order to obtain plate-moulds, for instance, which are much used, the method pursued will be evident by reference to Fig. 156.

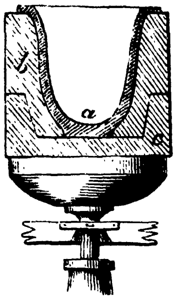
Upon a model A, which may be composed of metal, or, also of gypsum, and which exactly corresponds with the inner surface of the plate, but is in relief, a hollow gypsum cast B is taken, which serves as a matrix, and is saturated with oil; from this, as many casts C are taken as the matrix will bear; and these casts are now the actual moulds. As the gypsum expands in setting about 0.01 in linear dimensions, the original model must be made so much smaller. According to the form of the vessels to be constructed, the moulds are simple or composed of two parts. The clay is either pressed upon the mould in pieces with the hand (as is done in the case of feet, handles, and ornaments, which are always formed separately, and applied afterwards); or, in most cases (as with plates, cups, and all similar hollow vessels), the mass is rolled out into thin leaves or sheets, which are then spread over the mould, and pressed upon it with a wet sponge. These rolled sheets of paste, which are considerably thicker than the sides of the future vessel, as well as the moulds, are brought to the moulder by an assistant workman. The paste is frequently pressed upon the forms with more certainty of uniformity on the wheel,* when

Fig. 156.



* In England, a jigger or throw is generally used in this operation: it resembles a lapidary's-wheel, but is larger, and consists of a spindle, with a winch, pulley, and belt, fixed to work in a bench, and a block to fix firmly on the top of the spindle. This is used to give motion to the plaster moulds placed on the block.

Fig. 157.



the pieces are round, even with an ornamented surface. Thus, for instance, as represented in Fig. 157, where the sheet of paste *a* is pressed against the mould *e*, *d*, which is rotating with the disc of the wheel. In this case, the inner surface only is formed by the hand, and when this is inadmissible, on account of elegance of form or surface, the double moulds are used, as shown in Fig. 158, where the paste *c* is laid upon the solid form *b*, and thus brought into the mould *a*, Fig. 159. This new position is clearly shown in Fig. 160, in which *d d* represents cavities by which the inner mould can be removed. Metal or horn tools are also frequently employed for the removal of inequalities on the surface, but these are only applicable to vessels that can be formed on the throwing-wheel.

Fig. 158.

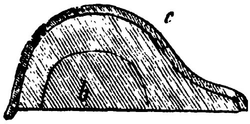
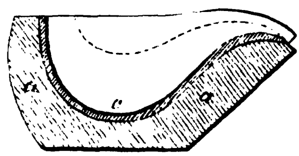


Fig. 159.



The use of these tools will be best understood by a description of the method of forming plates. Round slabs of paste are first prepared

Fig. 160.

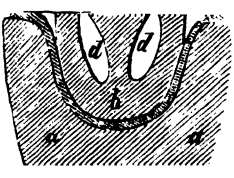
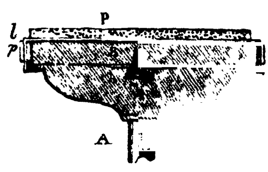


Fig. 161.

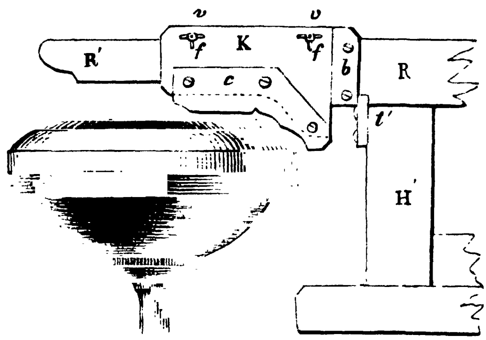


upon the wheel. The head of the throwing-machine *T*, Fig. 161, is furnished with a plug *S*, in the centre, which fits into a socket in the round slab of gypsum *R*, over which a piece of wet leather *l l*, is stretched, after the fashion of a drum, by means of the copper ring *p*. The lump of paste is spread over this, and is converted, by turning, into a plate *P*, which is brought to a uniform thickness by means of a ruler. Thus prepared, it is removed by means of the leather to a plaster mould resembling *c*, Fig. 157: this latter being fixed upon another wheel, which is rotated whilst the workman presses down the plate with a sponge dipped and moistened in slip.

In this manner, the inner side of the plate is formed, but the outer surface can only be made with the tool *c*, before mentioned, and shown in Fig. 162, which also reduces the mass of paste to the proper thickness; the tool is simply a piece of brass plate, in which half the

exterior outline of the plate is accurately cut. This tool is attached to the slide *b*, which can be moved upon the horizontal arm *R′*, *R*. The adjustment is managed by means of the screws *v v*, which pass

Fig. 162.



through the holes *f f*. The plate being made to rotate in contact with the edge of the tool, all the excess of paste that extends beyond the proper outline is cut or turned off, and the plate is then formed.

Fig. 163 represents workmen employed in *moulding* and *furnishing* the additional pieces, such as the spout, handle, &c.

Fig. 163.

The moulder *A* forms a thin sheet of the prepared paste *b*, with a roller on a piece of cloth or skin spread on a bench, and the workman *B* places it on the mould *m*, to which he makes it adhere, by strongly pressing it with a damp sponge. The mould *m* is placed on a circular plaster frame P, whose iron axis *f* is made to revolve at pleasure by the workman, thus enabling him to fashion it more easily. The workman *G* is moulding a handle *a*, for the sugar-basin *s*; he is removing the roughness, and filling up the cavities left by the moulding.

Moulding or forming by pressure.—Experience has shown, very often to the cost of the manufacturer, that the porcelain-paste is exceedingly susceptible of injury from the pressure exerted in moulding, and the effects of this are only made apparent at a period when it is too late to remedy the evil. When the pressure exerted by the fingers or moulding instruments has been greater at one part than at another, or when there has been a general want of uniformity of pressure, the various parts are very differently affected during the subsequent drying and firing; some shrink more, others less, and a general distortion occurs, which inevitably spoils the whole work.

These defects are not so apparent when slight pressure only is applied, and are consequently easily avoided in the ordinary process of moulding; but when the pressure is increased and applied more unequally, they become so marked and unsightly, that the pieces must be entirely thrown aside. It is for this reason that the use of moulding-presses, either as screw or other presses, is connected with such insuperable difficulties that they have been entirely discarded, except for particular cases, in the porcelain-works. Presses can only be applied to objects of such small dimensions as preclude the possibility of perceptible differences arising in the consistence of the mass. Amongst these are, for instance, coat buttons and the like, which are manufactured in England from tender porcelain.

Casting.—In moulding vessels by casting, which is only practiced with porcelain, no difficulties of the character just mentioned occur, but there are others which are not unimportant. The process of casting depends upon the phenomenon which we have witnessed in the ordinary plan of drying the paste upon slabs of gypsum, *i. e.* upon the power of absorption of the gypsum, which is due to its porosity. Something similar occurs in the subsequent glazing, which will be described below. If a dry plaster mould is dipped into water, a certain portion of the latter will be absorbed by the pores, which thus become filled; if the water was muddy, with suspended particles of clay, a kind of filtration occurs, and all the clay that was suspended in the absorbed water is left upon the surface of the gypsum, where it conglomerates and sets. The thickness of the deposit of paste depends upon the duration of the operation, upon the massiveness and degree of dryness of the mould, and, lastly, upon the nature and substance, or the dilution of the paste. A very plastic material and pure clay soon form a kind of impenetrable crust, which prevents any further increase in thickness, while the flux in the porcelain-paste retains the particles from coming into too close contact, and admits of absorption

taking place through the deposits which have already been formed. For the purpose of casting, the paste must be stirred up into a thick, but yet perfectly liquid slip, and this must be passed through sieves, that all granular particles and air-bubbles may be left behind. Suppose a milk-jug, like Fig. 164, is to be cast; the foot *c*, the body *b*, the neck *a*, and the handle *d*, will each be cast in a separate mould; these distinct operations are necessary, because prominent parts, like the lip of *a*, are not easily made. For this reason the neck *a* is moulded in an inverted position, as shown at *a*, Fig. 165; *m* and *m'*

Fig. 164.

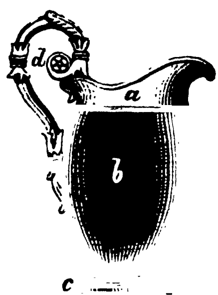
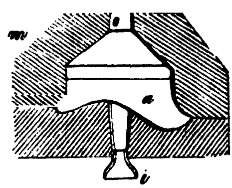


Fig. 165.



are the sides of the mould, *o* is the aperture through which the paste is introduced, *i* that through which it flows out. The same letters apply to like parts in the form for the foot, Fig. 166, in which *c'* is the space for the foot. Both moulds are first closed below, then completely filled with the liquid paste, from two to three minutes being allowed to elapse before the water is rapidly drawn off. A layer of one or two lines in thickness is then found to have collected. The mould for the body of the vessel *b'*, Fig. 167, is used in precisely the same manner,

Fig. 166.

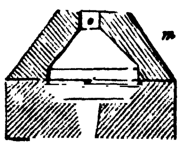
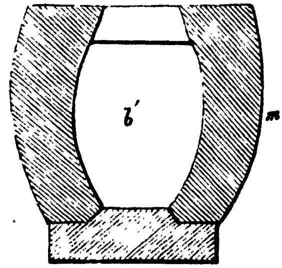


Fig. 167.



but is emptied by inversion. All the pieces, after having been cleaned from superfluous paste, are put together and joined while in the moist state, and when fresh, the joining is so perfect that no indication of where it occurred is perceptible. The handle is put on afterwards.

The methods of casting porcelain have not been brought to great

perfection, or carried out to any great extent; the pieces must necessarily remain in the mould for a considerable time, in order to acquire the proper consistence, and the operation consequently requires much time and many moulds. On the other hand, many articles can either not be cast at all, or only in pieces. From a bottle-shaped vessel with a narrow neck, for instance, the excess of clay can only be poured out by inverting the mouth, and the jerks with which the water then flows out, destroys and carries away the deposit upon the mould. The only method of casting such vessels is, therefore, to make them in two halves, and fit them together afterwards. At Sèvres, pipes, retorts slabs, palettes, &c., are regularly cast; as are also pillars, and the legs of furniture.

Turning and Finishing.—The pieces are never faultless or perfect as they leave the hands of the moulder, but require various, and often tedious finishing processes; such as, *turning*, *re-touching*, *ornamenting*; and, lastly, the adaptation of the separately moulded pieces to each other.

Many objects are made very much thicker on the potter's-wheel than they are intended to be when finished, and the excess is turned off in a lathe, that the proper uniformity of outline may be attained. This turning is precisely similar to that practiced with horn, wood, or metal, and the clay must be in such a state of dryness, that a connected shaving may be cut without either crumbling or adhering to the tool. In this state the piece is fastened to the gypsum slab of the throwing-lathe by moistening the bottom: the wheel is generally placed horizontally for this operation, and the pieces are fixed in or upon a choque, as is the case in an ordinary lathe. Instead of the chisel, ordinary flat sharp knives are employed as tools. The chief point in the finishing process, is the removal of the ridges which are produced wherever the mass has penetrated between the two meeting edges of the mould; these ridges appear again after burning, if they are removed by pressure, but not when cut away with the knife.

The casual cracks or indentations have also to be carefully filled up at this stage of the manufacture. The most tedious work of all, is that in which pieces have to be cut away with the knife, in order to produce the effect of basket-work, &c. An ornamental appearance is frequently imparted to the finished pieces in this state by pressing a kind of engraved stamp, in the form of a seal or roller, upon them. It is to be observed, that fatty oils will not prevent the adhesion of the stamp to the paste, when the latter is of the proper consistence, but that this is easily effected by oil of turpentine.

It has been already frequently mentioned, that handles, buttons, feet, ornaments, &c., are formed or moulded separately, and fixed upon the porcelain before it is burnt. The less simple of these parts are moulded in plaster moulds; smooth handles of uniform dimensions are obtained by pressing white clay through an aperture of corresponding diameter. A string or ribbon of clay is thus obtained, which only requires to be cut into lengths and properly bent in order to form a handle, such as is used for all ordinary vessels. All joints of

this kind are simply effected by sticking the pieces together, under very gentle pressure, after the two surfaces have been roughened and covered with slip. All changes, which, during drying and firing, affect unequally the mass of the vessel and the ornamental parts, tend to cause cracks, and to separate the latter. For this reason both parts should be equally dry, and the surfaces should have been prepared in the same manner (*i. e.*, both turned or cast in plaster), and all excess of slip is to be avoided, that the moisture which it contains, and which causes it to contract more in drying, may be without perceptible effect from its minute quantity. The same precautions apply to the joining of pieces moulded in separate forms, in which case the surfaces of juncture should be re-touched with a sponge or cloth.

Very fine net-work, as, for instance, the lace on the drapery of the small figures which are now in fashion, is made in a very ingenious manner, by dipping real lace into slip, which attaches itself to it, and is allowed to dry. The subsequent firing then destroys the original net-work inside.

Drying.—When the water, which every paste in the plastic state must and should contain, is removed by drying, the solid particles will be brought closer together, in proportion to the quantity of water which has disappeared, *i. e.*, a diminution of volume, or shrinking occurs; the proper proportions will remain unchanged when the shrinking and drying have been uniform throughout, but distortions will be produced if the latter is not the case. For this reason, the pieces cannot be dried in a stove, in the sunshine, or in a current of air, but only in the shade, and this is the more necessary, as experience has shown that pieces quickly dried only become dry on the outside, and enclose a quantity of moisture within the outer layer, which causes them to split in the furnace, often with a kind of explosion. The general practice is to leave the goods arranged upon wooden shelves until they lose no more moisture.

The Glaze.—In some places (Berlin, Nymphenburg, Meissen) the glaze is composed of kaolin, gypsum, and broken porcelain; it is, therefore, a glass containing alumina and lime, with no more potash than the small quantity which is contained in the felspar of the kaolin and in the broken porcelain. At Sèvres the glaze is composed, solely and alone, of the pegmatite from St. Yrieix, and consists, therefore, of quartz and felspar. Although the relation of these two constituents may vary very considerably in small pieces, yet this is of no moment at Sèvres, where such immense quantities are employed at once; the analyses of each cargo, as made there, and of the decanted glaze itself, in which all the constituents are mixed up into a homogeneous mass, hardly differ. The mean of these analyses is 74 silica, 17 alumina, and 9 potash (with a little lime and magnesia), which proportions correspond with the formula: $2(Al_2O_3,3SiO_3)+KO,3SiO_3$. Everything depends upon the proper fusibility of the glaze; if this is too difficult of fusion, it does not become sufficiently fluid to form a smooth, even surface, but appears wavy; on the contrary, a glaze that is too readily fused, becomes liquid before the paste is sufficiently

baked, and is still so porous as to suck in the glaze, in which case the surface appears rough and dry. It is obvious that all the ingredients of the glaze must be finely pulverized, decanted, and accurately mixed, in a similar manner as the paste itself.

Glazing.—Far the larger proportion of all porcelain-ware is coated with glaze, and this can only be quickly and uniformly spread over the surface by dipping the pieces into a vessel containing the glaze in the form of slip suspended in water. Vessels simply dried would absorb the water too slowly, and would be liable to bend and soften during the dipping; it is, therefore, necessary to fire them to a certain extent previously, in order to render them porous and capable of absorbing water with avidity, as also to counteract their tendency to soften or fall to pieces in water. The porcelain is called *biscuit* after having been thus once burnt; when dipped into the glaze, it absorbs a certain quantity of water, and the glaze which was suspended in that portion is left attached to its surface. The quantity or thickness of the glaze depends therefore, very much upon the massive nature and the porosity of the vessel immersed; it is also influenced by the amount of glaze held in suspension by the slip, by the length of time it is held in the liquid, and the degree of humidity of the biscuit. There are, consequently, many circumstances tending to render the deposit of glaze unequal, which must be counteracted by preparing a slip of the proper consistence, and by sufficiently burning the biscuit; when these have been properly attended to, an instantaneous (20 to 40 seconds) immersion is all that is required. The quicker the operation is performed, the more uniformly is the glaze disseminated, and that part of the piece which was introduced first into the glaze, is always removed first from the dipping-vessel. The part at which the piece is held by the workman, on removing it from the dipping-vessel, has to be subsequently glazed with the aid of a brush, and the glaze is removed from those parts which would cause the vessel to stick to the support of the furnace.

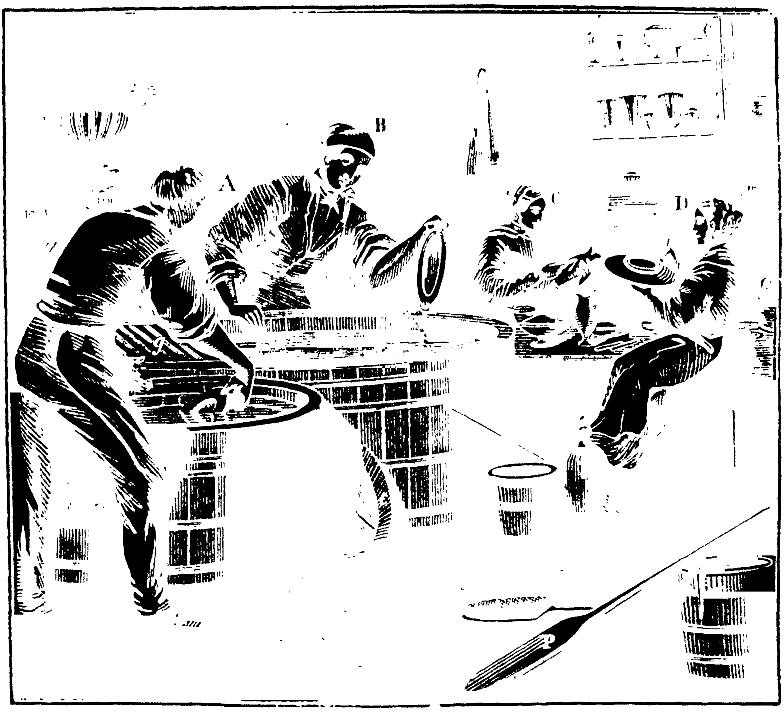
Fig. 168 represents the process of dipping the *biscuit*-ware in the liquid glaze.

The workman, *A*, is dipping a plate, holding it by the right hand, and plunging it into the liquid by the rim; he is bringing his left hand to receive it at the opposite side. The workman, *B*, dips it vertically, and holds it so as to allow the excess of glaze to run off. The female, *C*, is removing any drops of glaze on the body of a milk-jug which may chance to remain. The other, *D*, is doing the same to the bottom of a plate, in order that it may not adhere to the support on which it is placed for the purpose of drying.

Among the utensils lying about, are *g*, the wooden trellis upon which the pieces are placed as they are taken out of the trough; *t*, the sieve which is employed to separate the froth or impurities which float on the surface of the glaze; *P*, the shovel for agitating the glaze, so as to maintain it always of the same degree of consistency; *b*, a bottle of vinegar for mixing among the glaze; and at the side of *D* is a small cup, *c*, containing some glaze and a brush for re-touching

any of the cups, handles, plates, &c., in places which have not been coated with the glaze, or where it is too thin.

Fig. 168.



The glaze must of course not be allowed to settle down in the tub during the operation of glazing, or the vessels would be unequally glazed. It is generally sufficient to stir the liquid, or some substances are mixed with it which prevent the slip from being deposited; the effect of vinegar is extraordinary in this respect. Thus, for instance, glaze in water at 20° C. (68° F.), required $4\frac{1}{3}$ hours to separate; in water at 60° C. (140° F.), 3 hours; in water containing $\frac{1}{7}$ of vinegar, 6 hours; and in water with $\frac{1}{22}$ of gum arabic, 8 hours under the same circumstances.

If a thinner glaze is required at any particular part, the part must be moistened previously to immersion; places that ought to remain without glaze are covered with a mixture of wax and tallow; a portion of the glaze may be removed with a brush, or the whole by scraping.

Fig. 169 represents the various articles on their way to the kiln, on a plank on the shoulder of the workman *A*. These articles are very fragile, not having acquired, as yet, any tenacity. *B* is a workman engaged in repairing the seggar *c*, in which the various pieces of earthenware are placed before depositing them in the furnace.

The Furnaces, or Kilns.—The porcelain is fired with the glaze, in which operation it is rendered dense, vitreous, and translucent; it

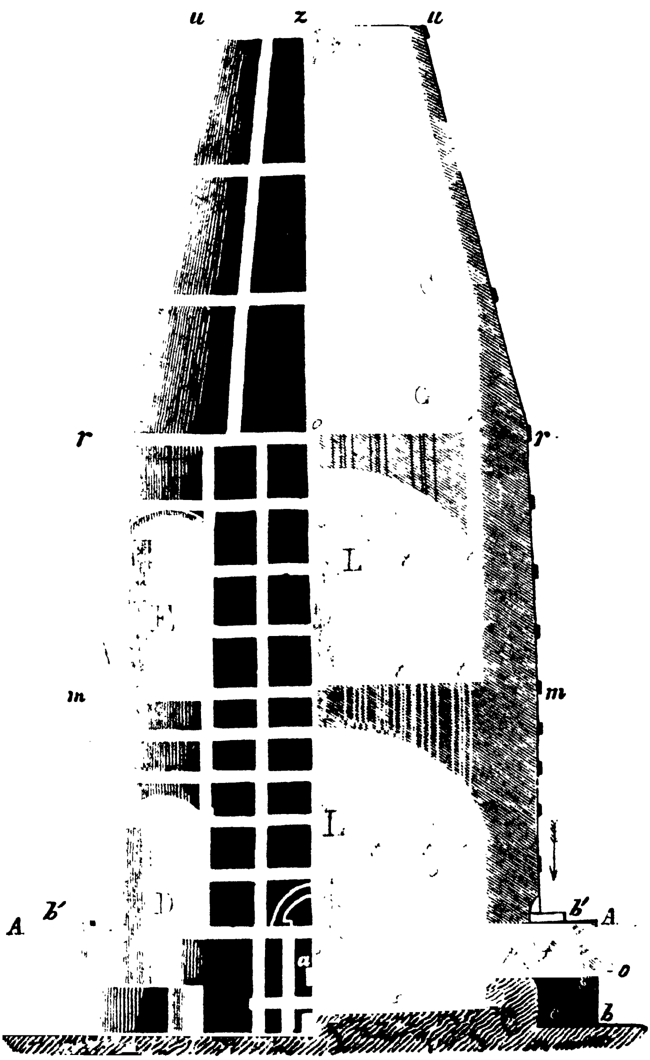
Fig. 169.

follows from this that the glaze must be of such a nature as to melt at that temperature which is necessary to bake the porcelain completely. The waste heat from this operation is employed for the production of biscuit, or for the firing previous to glazing.

The greatest possible heat that can be artificially produced is required for baking porcelain, partly on account of the chemical nature of the substance, and partly from the refractory nature of the glaze. This intense heat is so much the more necessary, as the white color of the mass, the transparency of the glaze, and its softness at a high temperature, prohibit the exposure of the porcelain to the direct flame of the furnace. Porcelain, like many other kinds of pottery, is, therefore, always enclosed, during firing, within clay vessels, or *seggars*. This high temperature, which must be easily regulated, uniform, and steady, if the pieces are not to be spoiled by splitting, bending, or fusing, as well as the large quantity of the material, and the number of seggars that are fired at once, requires commodious furnace arrangements, peculiarly adapted to the object in view. In the first place, it is obvious that the porcelain goods cannot be brought into direct contact with the fuel, or with the flame of the furnace, without im-

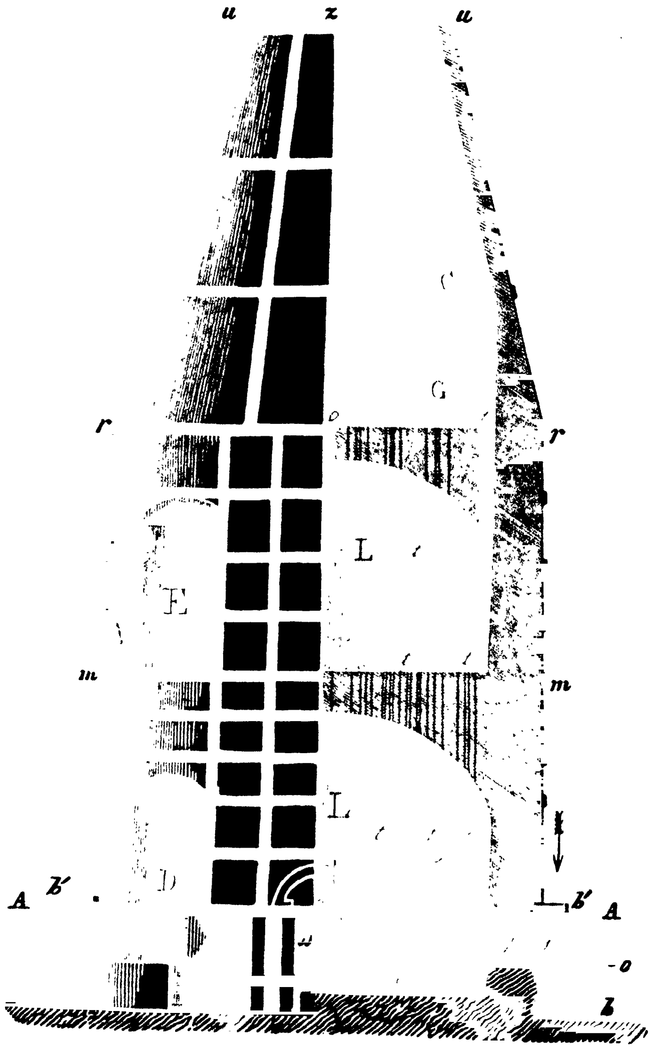
peding the draught and causing a want of regularity in the distribution of the heat. All pottery is consequently baked in a reverberatory furnace, the fire of which is made on a separate grate, and does not come into contact with the ware. All potters'-kilns are, therefore, reverberatory furnaces. They all have the advantage of surrounding the objects more completely with flame, and of heating them more uniformly than would be practicable if they were placed in contact with the fuel, and the regulation of the heat is also facilitated. The heat in a reverberatory furnace, like that shown at vol. i. p. 265, is very unequally distributed, being very much greater near the grate

Fig. 170.



than in the neighborhood of the chimney; this form of furnace is consequently not nearly so applicable to the present purpose as that employed in the glass-houses, where the fire is in the centre instead of at one end. The porcelain-kilns are, indeed, very similar to the glass-furnaces; the fire in the former, however, is made on several grates, situated at the circumference, instead of being united, as in the latter, into one central fire. The porcelain-kiln, therefore, consists of a round chamber, on the floor of which the porcelain vessels, enclosed in the seggars, are arranged in columns or *bungs;* from below, and all around, the flames ascend from a number of wide

Fig. 171.

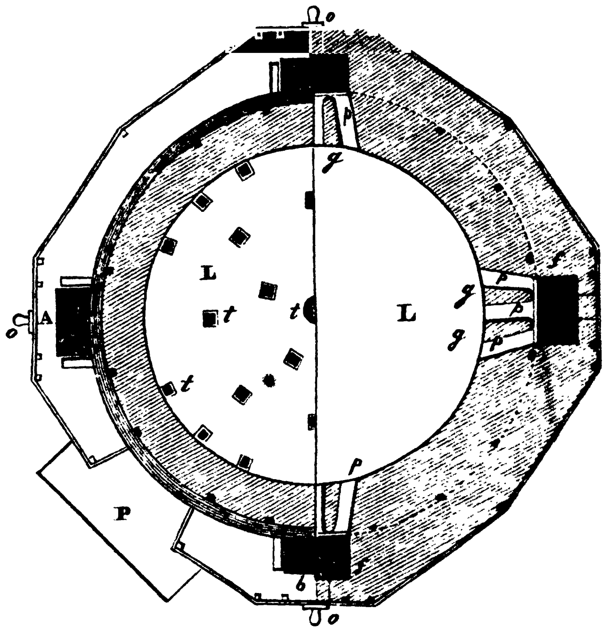


flues, which are in connection with the same number of fire-places. The flames fill the whole space, circulating between the columns of seggars, and escape through different apertures in the top of the chamber. From thence they enter a second floor, as it were, and are employed for heating the biscuit-ware. The details connected with the kiln will be seen by reference to the Fig. 170, which represents the Sèvres kiln, the one-half in perpendicular section; whilst Fig. 172 shows the horizontal section, on the right hand through the fire-hearths, and on the left, a section through the upper chamber. The kiln is surrounded by 4 separate fires, *A*, *A*, *A*, *A*, which first heat the space *L*, destined for completely burning the porcelain; then the upper chamber *L'*, for baking the biscuit, and, lastly, a third space *G*, which may be used for the same purpose or for baking the seggars, the flame escaping through the chimney *C*. The hearths of the porcelain-kiln are quite peculiar, and are constructed without any grate, and in such a manner that the draught is forced to take a direction contrary to that which is usual in other furnaces. The space *c*, is filled with red-hot charcoal; the wood is then introduced in small billets, which just pass through the aperture *b'*, and completely fill the space *f*. The draught, therefore, assumes in the first instance a downward direction (in the direction of the arrow) through *b'* and the spaces between the billets of wood in *f*, reaches the burning wood between *f* and *c*, and creates a long flame, which escapes through *p* into the chamber *L*, where the combustion is completed. In an ordinary fire-grate, the glowing fuel is brought into direct contact with the cold air, whilst in this arrangement the centre of the combustion is fed with air that has already been warmed in passing through the upper layers of wood; all the radiant heat is collected also by these upper layers, and while in an ordinary fire the flame has to pass through the freshly-added fuel, and is cooled, the contrary is here the case, and the combustion is consequently more complete: the whole hearth being composed of bricks, which are bad conductors of heat, and the velocity of the draught diminishing in the wide chamber *L*, more time is allowed for the perfect combustion of the volatile products from the fuel.

The round aperture *o*, is generally closed with a clay stopper, and is employed for stirring the fire; *b*, at the foot of the hearth, serves for removing charcoal and ashes when it is necessary. The draught is regulated by means of the lid of *b'*. The aperture or flue is divided by the tongues, *g*, *g*, into three channels, *p*, *p*, *p*, in order that the flame may be more dispersed. *D* and *E* are the doors for the insertion of the goods. In the arched covering of the space *L*, twenty-five apertures, *t*, *t*, are left to conduct the flame into the chamber *L'*. A single opening in the middle would draw all the flame together instead of spreading it. For the same reason, similar openings, but only half as many, *t'*, *t'*, are made in the roof of *L'*. Small openings, *v*, are made in the walls of the chamber *L*, for observing the color of the fire, and for the introduction of small samples or watches (montres) into the seggar nearest the hole, in order to judge

of the progress of the firing. These samples are simply fragments of biscuit covered with glaze, the appearance of which, and the de-

Fig. 172.



gree of fusion which they undergo, afford a clue as to the state of the porcelain vessels. The back part, *y*, *y*, of the tube, Fig. 173, is introduced from the outside into the aperture *v*; this tube is closed in front by a plate of glass, to prevent the access of air, and is also supplied with an iron damper, *z*, which slides in the frame, *h*. The furnace, which is generally above twenty feet in diameter, and twice that height, is constructed internally of fire-stone, surrounded on the outside with a layer of ordinary bricks. The whole is bound together by iron, *m*, *r*, *u*, *z*, to keep it from falling to pieces, which would be the infallible result of the great expansion by heat; the iron girders are connected together by elastic hooks, to prevent them from bursting.

Fig. 173.

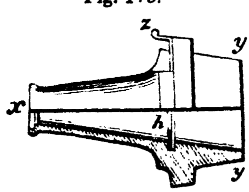
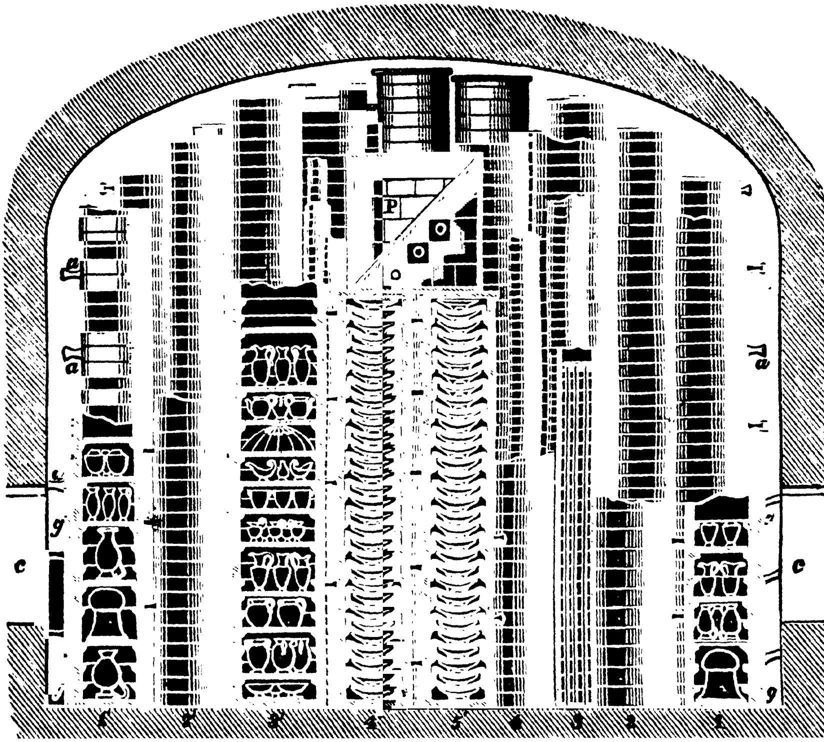


Fig. 174 represents a vertical section of the porcelain-kiln, as charged at the manufactory of Sèvres. The piling of the seggars one upon another is here shown; some of them are seen in profile, as at 2, 2′; others in section, to show the ordinary contents, such as plates, in 4′, 5′, arranged on Regnier's plan; vases, jugs, &c., in 1, 1′, 3′; tubes suspended in 3, and a porcelain slab at *P*. *c*, *c*, are partitions which divide the flame at its entrance to the kiln; *a*, *a*, *a*,

props for sustaining the seggars; *g*, *g*, *g*, are plates of refractory clay, called fire-guards, which prevent the flames and ashes from coming into direct contact with the seggars.

Fig. 174.



The German furnaces are not materially different; they are heated by five fire-places, and the apertures *t* and *t'* are not so numerous (only 7). These are wider, and furnished with short chimneys, which project into the chamber *L'*.

Double Furnaces.—It might naturally be expected that a considerable saving would be effected by constructing one furnace above the other, or by supplying fire to both floors, and obtaining the greatest heat in both. In the fires of the upper floor, fuel would be saved in proportion to the amount of heat derived from the lower arch. This idea has, in fact, been carried out at Sèvres, but the result has not answered the expectations of the inventors.

Porcelain-kilns last much longer than glass-furnaces, not being subject to the destructive action of the volatile alkalies. The kilns at Sèvres last, on an average, 300 firings; in other places, several have lasted 30 years, or 1,500 firings.

A dry foundation, which exerts as little cooling influence as pos-

sible, is an important point, the kilns having been found extremely susceptible in this particular.

The Fuel.—The manufacture of porcelain is very much more circumscribed with reference to the fuel that can be employed, than any other. It will be conceived, from what has been stated above, that those kinds of fuel which burn with flame are indispensable, and are valuable in proportion to the length and vigor of the flame which they afford. A second, no less necessary property of the fuel is, that it should discharge as little dust and ash into the kiln as possible, for this, after penetrating between the seggars, produces black spots upon the glaze. For this latter reason, wood is almost universally employed, and it is seldom that, as at Meissen, coal or brown coal can be used.

Amongst the different kinds of wood, preference is given to the light varieties, as poplar (at Sèvres), pine-wood (in Germany), and the wood is cleft into small billets. By this means, more wood is consumed at once, and a larger flame is produced, than is the case under the same circumstances by any other process. The wood is not artificially dried, but is only dried in the air, in which state it retains from 6 to 10 per cent. of moisture. The use of peat has been tried at Berlin, but without satisfactory results as regards the quality of the goods.

The insertion in Seggars.—It is quite impossible, as has already been stated, to bake the finer kinds of clay-wares, and particularly porcelain, freely exposed to the fire; they require to be placed in clay boxes or cases, so-called *seggars,* in order that the glaze may not be injured. These indispensable vessels are of such importance, and so materially affect the quality and price of the porcelain, that they merit particular notice in this place.

The seggars, and what pertains to them, must be more difficult of fusion and less easily softened than the porcelain vessels which they enclose; they must also be capable of expanding by heat without breaking or cracking; and be composed of a material that is not difficult to form, and is not too hard, that they may be ground after burning; and, above all things, they must contain no substances that will cause decrepitation in the kiln, so as to cover the porcelain vessels with sand or dust, which would inevitably destroy the glaze. If, in addition to these requisites, the seggars must possess the amount of strength necessary to support the weight of a whole column of them, piled up the one upon the other, it will easily be conceived that any porcelain-manufactory must be particularly favored in possessing in the neighborhood a material suited for these vessels. Their quality, as might be anticipated, is very variable in different localities. As a general rule, the seggars are constructed of plastic clay, and so-called cement. The former imparts the property to them of resisting the fire, but shrinks to such a degree of itself, that the seggars would crack if cement did not also enter into their composition, a substance which is either totally incapable of shrinking in the fire, like sand, or which has already shrunk, as the ground fragments of old seggars.

The degree of fineness, the grain of the cement, is of importance, and also the temperature at which the shrinking chiefly occurs.

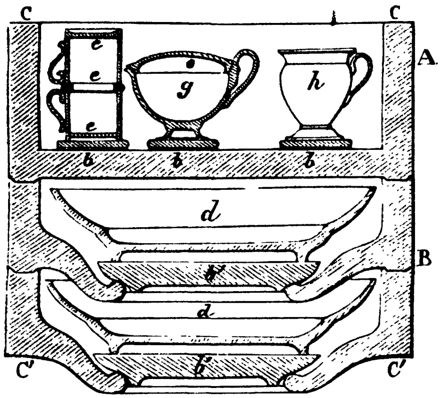
Composition of the Seggars.—At Sèvres the body of which the seggars are composed consists of $\frac{2}{5}$ plastic clay (sometimes decanted, at others a mixture of better and commoner sorts), and $\frac{3}{5}$ of ground fragments of seggars, or the same quantity of a mixture, consisting of equal parts of fragments and crushed quartz-sand. At Meissen they use $\frac{3}{5}$ clay to $\frac{2}{5}$ cement; at Berlin, $\frac{2}{3}$ clay to $\frac{1}{3}$ cement. Whilst at Sèvres the seggars last 15 firings or more, at Vienna they last but 4 or 5, and at Berlin, only 2 or 3 firings. At the last locality, the loss occasioned by the seggars becoming useless amounts to 30 dollars = £4 10*s.* at each firing; in Meissen, 20 per cent. of the seggars are lost at each firing. These differences depend solely upon the local inequalities of the plastic clay, even from the same deposit, and the loss is so much the greater because the bad seggars cannot be piled so high in the kiln as the good ones. The seggars have been observed to suck up the glaze from the vessels, that is to say, they facilitate the volatilization of the potash by exerting a chemical attraction for it, absorbing it on their inner surface and becomiug glazed; this may be remedied by expressly glazing the surface of the latter. It is of the utmost importance to pay attention to the shrinking of the clay vessels on introducing them. In the softened state, the latter often become bent when any obstruction prevents them from shrinking uniformly, the unevenness of the seggar bottoms often renders it necessary to support the pieces by other special means.

Form of the Seggars.—The form which is given to the seggars is a point of still greater importance, because the quantity of goods which can be placed in the furnace at once depends upon it, and upon the mode of their arrangement; the greater the number of vessels that can be fired at once, the more the cost of firing will be lessened; for, in each single piece, the economy in the process is mainly dependent upon the mode of packing the furnace, the heat costing the same, whether the furnace be entirely or only half filled. Hence all the seggars are made in the form of shallow cylinders, except when particular cases demand an exception. Originally their bottoms were flat and even, and each seggar formed the lid to the one placed below it, as is also still the case for smaller vessels, several of which can be placed in one seggar (Fig. 175). That these may rest upon a perfectly even surface, they are placed upon smaller ground plates *b b b*, consisting of the same material as the seggars, and which can easily be changed or repaired: the glaze must be carefully removed from those parts of the vessels which rest upon the horizontal support, or wherever they come in contact with each other; and even in those parts which are free from glaze, but subject to soften and adhere in consequence, sand is strewn to prevent such from occurring.

Since the year 1800, the seggars destined to support hollow vessels, such as plates, saucers, pans, &c., have been constructed with a bent bottom, so that the bottom of each upper seggar projects down-

wards into the hollow part of the vessel contained in the seggar below it; space is thus economized, and from 29 to 30 plates can be packed in seggars in the same space as was formerly occupied by only 20. At the same time, the bottoms of the seggars c' c' c', as shown in Figs. 175, 177, are open, and are filled up by the pieces b' b'. By this means, the material of the seggars is better capable of withstanding the action of the heat without breaking.

Fig. 175.



Lastly, a form of seggar was introduced at Sèvres in the year 1839 by Regnier, which is still more commodious. Upon this plan, as will be seen in Fig. 176, a plate, for instance, is enclosed in a double seggar, an outer and an inner one. In the outer one, the bottom is entirely wanting; it consists of a single ring t t, with projecting ledges on the inside, which support the plates and their respective seggars

Fig. 176.

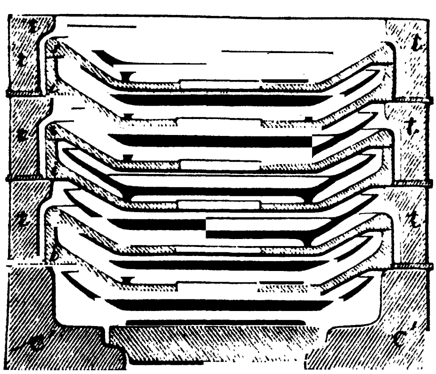
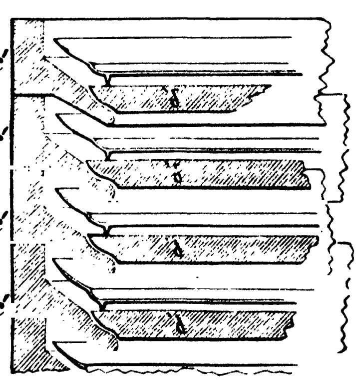


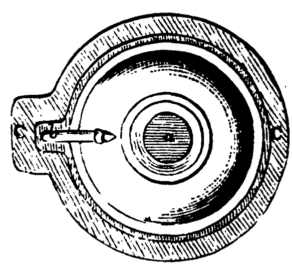
Fig. 177.



i i, and s s s. Every two seggars i and s, form in this manner one close vessel, the sides of which are formed by the perpendicular rim of the lower seggar i, the upper one s, having no rim. In each vessel of this kind one plate is enclosed, and a second plate is supported between each pair of seggars. The necessity for the different form of the lowest seggar C' is obvious. In this manner, from 51 to 52 plates can be fired in the same space as was occupied upon the old plan by only 20, and afterwards by 29 to 30. The economy of space, which amounts in the height to about 75 per cent., does not exceed 45 or 25 per cent., with less flat-shaped vessels; on the other hand,

the cost of firing 100 plates, including all possible items, upon the former plan, was 110 frs. = £4 8*s.*; upon Regnier's plan, 70 frs.; and, therefore, 36 per cent. less in favor of the latter. Many vessels which, on account of their undulated form, are apt to become distorted in the fire, require supports to keep them straight. In Fig. 175, for instance, the two cups *e e*, placed one above the other, are separated by a ring *c*, in which a groove is made both at the top and bottom to receive the edge of each cup; the goblet is also furnished with a lid *o*, which does not belong to the vessel itself, and is only employed to retain the edge of a circular form; the rim *v*, of this lid is conical, so that the lid may rise in proportion to the shrinking of the vessel. For larger vessels with handles *b*, Fig. 178, which are burnt in great numbers at once, the seggar *c c*, is furnished with a prominent part for the support of the handle.

Fig. 178.



The success of the firing, all the seggars being properly arranged and cleaned, can only be attained when all the articles in the kiln receive an adequate amount of heat; the proper mean must, therefore, be observed between too little heat, which would leave them incompletely burnt, and too much heat, which would partially fuse them. The seggars must be safely piled, so as not to fall, and the glaze of the vessels properly secured from dust, and from the possibility of adhering. It must be remembered that all parts of the kiln are not equally hot; the mode of building the kilns secures a uniform distribution of the heat, but not an equally intense heat everywhere, those parts immediately in front of the stoking-holes being very much hotter than such as are situated between them. At different heights a different temperature also prevails. Immediately at the bottom, the heat is least intense, acquires the greatest intensity about the middle, and diminishes again towards the roof. It has already been stated that the seggars are piled up in columns, or bungs, one over the other, and these columns rest upon a very narrow base as compared with their height; by the contraction and expansion of the separate pieces, an alteration in the centre of gravity may sometimes occur, sufficient to cause the fall of the whole column, which then of course carries with it the neighboring columns, and the whole is reduced to a mass of fragments. A break-down of this kind is sometimes occasioned by the lower seggars, which are, however, purposely made stronger, being too weak to support the upper ones, and for this reason the height of the columns is proportionally lessened (as in Berlin) as the quality of the seggars deteriorates.

The arrangement or setting up of the seggars in the furnace requires, consequently, great experience and every possible precaution. Care must be taken to place the massive pieces in the centre of the furnace where the heat is greatest, and the thinner, more easily bent articles, in less heated parts. Immediately in front of the fire, nothing would

withstand the heat, if the seggars in that position were not protected by hollow semi-cylindrical screens, composed of clay (Fig. 174). In former times the mass composing the vessels was expressly prepared of different characters, and suited to the variable intensities of the kiln. The tendency of the seggars to lean and fall, is prevented by forcing clay, or something of that kind, between each pair, until the plummet indicates the whole pile to possess a perfectly perpendicular direction. The several columns are also supported against each other by the introduction of pieces of broken seggars. At the same time, it must not be overlooked that sufficient space (from 2 to 4 inches) is left for the flame to pass between the columns, and envelop the whole charge. The columns are, consequently, not only arranged at certain distances from each other, but also in a symmetrical manner. A portion of the ash, carried mechanically with the flame into the furnace, is sometimes deposited on the floor, and fusing with the lowest seggars, cements them so firmly together, that they can only be removed piece by piece. A layer of sand on the floor, however, completely prevents this from taking place. Opposite the testing-apertures in the walls, are placed the seggars for the reception of the watchmen or tests, with corresponding apertures in them.

Firing.—When the kiln has been charged, the apertures are closed, and the firing begins. Two distinct stages are observed in the firing: the first is intended to expel the moisture which may still remain in the vessels, and gradually raise them to a red heat; the second is that requisite for completely baking the ware. In the mode of heating, the two stages are distinct. In the beginning the firemen keep the upper aperture of the fire-hearth closed, and the plate *b'* is only removed for an instant at a time, when fresh wood is thrown upon the fire. The draught, therefore, enters through *b*, and travels in the same direction as in an ordinary fire, and produces a smoky, unclear flame. The wood is thrown in irregularly in thick billets, so that they cross each other in various directions. When the furnace has attained in this manner a cherry-red heat, which is seen through the test-holes, the space *f* is filled up to *b'* with logs laid parallel about 1 to 1½ inches in thickness, and which are just as long as the hearth is broad; the lower opening *b* is then closed. The baking now begins; the draught is reversed and the heat increased, the smoke disappears entirely, and nothing visible escapes from the chimney but a stream of hot transparent gases. During the process of baking, the draught is so great, that the charcoal is completely consumed, and all the ash is carried away by the draught. After the firing, there is not a cubic foot of ash and charcoal together, while the mass of wood consumed would alone yield 2 cwt. of ashes. The least irregularity in stoking is immediately perceptible in the working of the fire; the heat of the kiln diminishes directly on that side where the fire is badly attended to; this is best avoided by making the firemen change places every hour. As soon as any one of the fires is out of order, the red-hot charcoal is not perfectly consumed, and stops the progress of the flames, which consequently beat back. The charcoal must then be

brushed away as quickly as possible. New or repaired parts of the furnace exert a similar action. It once occurred at Sèvres that the one-half of a furnace had been newly built, and the ware at the side recently built was thoroughly burnt 2 or 3 hours before that on the other side. An old furnace always works slower, and the firing takes from 5 to 6 hours more than in a new one. In most places, the warming occupies half as long as the baking; the former last 7 to 8 hours; the latter, 11 to 13; sometimes the time is nearly the same; at Berlin the warming occupies 12 to 15 hours, and the baking 17 to 18; or the warming takes the longer time, as is the case at Sèvres, 15 to 18 hours being required for the first operation, and from 10 to 12 for the second. The temperature on the upper floor amounts to about from 30° to 60° Wdgw.; that of the lower floor, from 130° to 160° Wdgw. At the base of the latter the heat is less intense* by 40° Wdgw.

In Vienna, for every firing about 7 klafters (=about 16½ stacks)† of wood are used; in Berlin 700 cubic feet (=about 10 stacks). In Sèvres the consumption amounts to 65 stères‡ (=41½ stacks), as the mean of 12 observations in a double furnace with two great or baking fires. The consumption amounted at first to 73 stères, and sank at the end of 12 months to 52 stères. The mean quantity of porcelain baked during that time was 784 kilogr., which with the seggars required for encasing it, amounted to 14,000 kilogrammes. The mass of the seggars, therefore, amounts to 18 times that of the porcelain. In the kiln, as represented in Figs. 170, 171, 1 kilogr. of porcelain costs 2 frs. (=38 cts.) to burn, and the cost of 1 cubic foot of space in the furnace is 1 fr. 1 c. (about 20 cts.)

As the glaze of porcelain is a true glass, and this also enters into the mass, the process described at page 20, must also here be carried out; the porcelain must be annealed, *i. e.*, it must be cooled slowly

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* The instrument introduced by Wedgwood, and called by him *pyrometer*, or measurer of heat, is really only an appropriate empirical test for estimating the degree of heat in the furnace, and is by no means a proper instrument for the measurement of temperatures. The contraction of the clay is the principle upon which the measurement is made. Small cylinders are exposed to the fire, and by their diminution in diameter, the heat of the furnace is estimated. If all kinds of clay diminished equally in bulk by the same degree of heat, or even if the same kind of clay always shrunk in proportion to the increase of the temperature, the indications of the pyrometer would then be comparable with each other, and would afford an accurate mode of measurement. That this, however, is not the case, is shown at page 251, and it is purely accidental when two cylinders, placed side by side in the furnace, exhibit the same amount of contraction. For the potter, however, the instrument always affords a useful approximation, although it cannot be used for scientific purposes. It can naturally only be ascertained with little certainty and by indirect means, what relation the degree on Wedgwood's pyrometer bears to the degrees of the mercurial thermometer; the zero of Wedgwood, however, expresses nearly 580° C. (1,076° F.) and each additional degree (of which there are 240°) about 72° of Celsius (=130° F.), so that the greatest heat in the baking-furnace will be between 11,000° and 12,000° C. (=19,832° and 21,632° F.). None of the pyrometers which depend upon the expansion of bodies, or upon their degree of fusibility in the fire, come up to what is required of them, so that both science and art are still in want of a thermometer that shall indicate with accuracy very intense degrees of furnace temperature.

† Stack=100 cubic feet, Hessian.

‡ Stère=1 cubic metre.

in order to prevent it from becoming brittle. No separate kiln is employed for this purpose, but after firing, the kiln is simply bricked up and left with its contents until it has become sufficiently cool to be emptied, and this is generally the case after from 5 to 8 days; it is desirable, however, to open it the evening before the porcelain is removed.

On removing the baked utensils from the seggars, the sand which may have attached itself to them where they rested on the seggars, is ground off by a piece of sandstone, (or soft artificial stone,) which is used as a kind of file. A certain portion of the ware is always spoilt by bending, and must be thrown aside; in Vienna, for instance, three plates out of four only are sound. The perfect goods have also some faults which demand attention. Dark points are always visible here and there upon the glaze, which arise from minute grains or splinters that separate from the seggars, and falling upon the glaze, adhere to it. All those parts likewise which have been in contact with the supports are deprived of glaze. These parts are dull, void of lustre, rough, and can never be kept so clean as the glaze; this is of less consequence on the bottom than on the edges, unless the exact fit of a lid has left a rough seam round the latter. It is the ordinary practice to glaze those parts subsequently, by means of a brush, and expose them again to the furnace, which practice is of course attended with all the risk and cost of the first firing. When an easily-fusible lead-glaze is burnt upon those parts in a muffle, they by no means acquire the high degree of hardness which characterizes porcelain. For these reasons, it is now common to apply the grinding-wheel, with which the spots are removed, also to the edges, in a manner similar to that described for polishing glass. The inequalities are first removed with a stone; the scratches which this leaves are then effaced by the grinding-wheel, and the last polish is given with tin-ashes. This plan admits of more scope in placing the vessels in the furnace and in omitting to glaze them at different parts, and the best ground for gilding is thus obtained.

The color of porcelain is milk-white, without any tinge of blue; the qualities, which accord it the highest rank amongst the clay-wares, are the entire absence of porosity, the very intimate connection of the glaze with the mass, and the indestructibility of the former under the knife or when exposed to changes of temperature. It can only possess these properties when the fluidity of the glaze and the complete baking of the mass occurs at the same moment, and when both are nearly equally expansible by heat. The similarity in the nature of the flux and of the glaze exerts the greatest influence upon this latter quality.

The shrinking or contraction.—The most important change which porcelain, in common with all other pottery, undergoes, is the diminution of volume after firing, or the *shrinking*. This property of contraction alters with the least change in the quality of the body, but is precisely the same for the same body, so that the amount which occurs can be accurately estimated beforehand. According to ex-

periment, the linear contraction (*i. e.* the shortening in one direction, or that which a rod suffers in length) is about 13 per cent. as a mean; it can, however, fall as low as 7 or extend to 17 per cent. The contraction in volume is 39 per cent. in mean. About a fourth of the contraction occurs during the first heat, and the remaining three-fourths in the great fire; and, in the case of porcelain at least, there are two distinct causes connected with the temperature which account for it, viz.: the evolution of all the water, and the incipient fusion when the mass is thoroughly baked. The amount of contraction is for this reason in some measure dependent upon the manner in which the mass was formed, upon the amount of moisture which it contains, and the degree of pressure to which it has been subjected. Cast utensils shrink the most; those which have been moulded on the throwing-wheel, less; those which are pressed in moulds, still less; and pressed objects, the least of all. This likewise explains why those portions which have been submitted to less pressure, project, after firing, beyond those which have been more forcibly pressed.

Density.—A mass of porcelain must necessarily become specifically heavier as its volume is diminished; the specific gravity of the dry mass, once heated, has been found = 2.305; after having been thoroughly baked it is = 2.478. This applies to the mass in entire pieces, including, therefore, the pores. It is remarkable, however, that the contrary is the case when the mass is separated from the pores, and the specific gravity is taken in the state of fine powder; the specific gravity of the mass itself is then found to diminish with the increase of temperature to which it has been exposed, and with the amount of contraction it has experienced. Thus it has been found by:

		G. Rose.	Malaguti.
In specimens of		Specific Gravity.	
Once heated porcelain	Adhering to the tongue	2.613	2.619
After 3 hours in the great fire	"	2.589	2.440 half baked
" 4 hours in the great fire	"	2.566	
" 9 hours - -	No longer adhesive.	2.452	2.242 thoroughly baked.

According to this the cubic foot of really solid substance, weighing 82 lbs., is reduced to 70 lbs., a circumstance which is accounted for in a twofold manner. In the first place, nearly all bodies are rendered specifically lighter by the transition from the crystaline to the melted vitreous state, as is the case with the felspar employed in the Berlin manufactory, the specific gravity of which is 2.592, and is reduced after fusion to 2.384; the kaolin is diminished in the same manner from 2.633 to 2.562. The expansion may also be the result of a partial chemical reaction of the ingredients, and this is rendered still more probable by the specific gravity of the mass not corresponding with the mean specific gravity of the ingredients. The separate

particles of the porcelain are, therefore, permanently expanded during baking, but at the same time they are brought into closer proximity with each other. The goods that have been once heated are not altered in weight by being thoroughly baked in the great fire. The contraction of the mass composing the seggars is very much smaller, and often imperceptible.

Chemical Composition.—The analysis of porcelain has led to the following results:

Place of manufacture.	Silica.	Alumina.	Potash.	Protox. of iron.	Magnesia.	Lime.	Analyst.
China, vase	70.5	20.7	6.0	0.08	0.01	0.05	—
China, plate	53.5	28.5	5.0	0.08	trace	0.06	—
Berlin	66.6	28.0	3.4	0.70	0.6	0.3	Laurent.
Vienna (1806)	61.5	31.6	2.2	0.80	1.4	1.8	Laurent.
Meissen	57.7	36.0	5.2	0.80	traces	0.3	Laurent.
Paris	58.0	34.5	3.0	—	—	4.5	Laurent & Malaguti.

Porcelain-painting.—Porcelain is certainly best adapted of all the clay-wares for ornamenting with pigments and metallic lustres. The surface to which these decorations are applied being a true glass, porcelain-painting may be viewed as a branch of the art of glass-painting, the effect of which, however, is solely calculated for reflected, and never for transmitted light. All porcelain pigments are colored glasses, which acquire lustre and stability by fusion (or firing). Every pigment must therefore consist of a *coloring material* (generally a metallic oxide, those colors which are destroyed by heat being of course inapplicable), and the requisite addition for the formation of glass, or the *flux.*

The metallic combinations below are used as coloring matters, and produce the following colors:

1. *Oxide of chromium*, green.
2. *Oxide of iron*, red, brown, violet; black, gray, sepia, yellow tints.
3. *Oxide of uranium*, orange yellow, black.
4. *Oxide of manganese*, violet; brown, black.
5. *Oxide of cobalt*, blue, gray, black.
6. *Oxide of antimony*, yellow, different tints.
7. *Oxide of titanium*, yellow.
8. *Oxide of copper*, green. *Suboxide of copper*, red.
9. *Sesquioxide of iridium*, beautiful black.
10. *Protochromate of iron*, brown.
11. *Chromate of lead* (and chromate of barytes), yellow.
12. *Chloride of silver*, as an addition to carmine and purple.
13. *Purple of Cassius*, purple.

It will be easily conceived that transparent and opaque colors (enamels) may be used with similar effect upon a white and almost opaque ground, like that of porcelain, and, indeed, both are employed. Transparent colors are rendered opaque by means of *oxide of tin.*

Oxide of zinc, which imparts no color to glass, is, nevertheless, an important addition for enlivening the different tints, a property which is peculiar to the oxide of this metal. The sulphur-yellow colors of antimony are improved by it.

It is a well-established law in chemistry that the reactions of bodies are very much modified by temperature, and this is the case with the compounds above named.

The property of communicating color to glass is confined within certain limits of temperature, beyond which the color varies, or is altogether destroyed. A very important classification of the colors is founded upon this fact; they are divided into such as will stand the most intense heat of the baking-kiln, and can be burnt in with the glaze, and such as would afford no color (on account of volatilization), or a very imperfect tint, at that high temperature; these latter are the *muffle colors*, which are always applied and fixed in the muffle, after the vessels have been glazed. That these easily fluxed colors may not run and penetrate into the glaze, the firing must be accomplished at a temperature far short of the fusing-point of the body or glaze. While the muffle colors are painted on the glaze, as it were in relief, and can be distinguished as projections by the touch, impairing thus the lustre and smoothness of the vessels, the more refractory colors do not necessarily alter the level of the glaze, but are applied below or with the glaze. This is a great advantage, as the soft muffle colors, which always contain lead, are very much more subject to wear away. The firing of the refractory colors requires no additional expenditure, while the burning in the muffle is a constant source of expense.

Refractory colors are: *blue* with *cobalt; green* with *chrome; brown* with *oxide of iron, oxide of manganese* and *perchromate of iron; yellow* with *oxide of titanium; black* with *oxide of uranium.* It is to be remarked that these refractory pigments generally impart a very intense color, so that they can be used in very small quantities, and consequently exert no liquefying action on the glaze, or on the mass of the porcelain. They are either applied to the biscuit-ware, upon or with the glaze. The silicate of an alkali is used with them as a flux.

The muffle colors are applied with a great variety of fluxes, the chief of which, however, may be confined to seven, and the constituents of these will be seen in the following list:

Sand or quartz,	Saltpetre,
Felspar,	Potash,
Borax and boracic acid,	Soda,
Minium or litharge.	

Gilding, &c.—Gilding is executed on porcelain in the usual manner, the gold being first prepared in a pulverulent form. A solution of gold in aqua-regia is precipitated with green vitriol; the gold thus obtained in the state of a brown powder is washed, dried, and then mixed with about $\frac{1}{10}$ of oxide of bismuth (basic nitrate), and rubbed up with thickened oil of turpentine. The mixture, or the gold color,

can then be applied with a brush, and fired in the same manner as the other colors. The oxide of bismuth forms a flux with the surface of glaze, by means of which the gold is firmly attached. It has a yellow and dull appearance on leaving the muffle, and acquires the metallic lustre by burnishing with agate.

Platinum black or platinum sponge can be applied in precisely the same manner as metallic gold.

In Meissen they use a preparation in which the gold is held in complete solution in the oil of turpentine; a coating of this solution leaves after burning (over a spirit lamp for instance), a bright metallic surface upon porcelain, which, however, is less durable than that obtained in the ordinary manner. The mode of preparation is kept a secret in the manufactory.*

Firing.—The firing of the more fusible colors and the gilded articles is executed in the muffle, the arrangement of which is not essentially different from that described and shown at page 139. As a certain amount of heat is essential to the success of the operation, pyrometrical tests are applied for ascertaining the necessary temperature. A convenient test for this purpose, is afforded by the variations of color through which the gold-purple passes when submitted to a gradually increasing temperature. In practice, six gradations are made standard points by the porcelain-painters, which correspond with six degrees of temperature that are of practical importance. A fragment of porcelain colored purple with gold, and held in the muffle attached to a platinum wire, becomes gradually:

	Corresponding to	0° C.
Of a dirty-brown-red	Gilding upon colored ground	620
Brick-red Ditto passing into rose, red on the edges and thinner parts	Re-touching	800
Rose color passing into purple	Easily fusible colors	900
" passing into violet	Gilding upon glaze	920
" passing into deep violet Violet becomes lighter	" upon plate edges More difficultly fusible colors	950
Rose color has disappeared, and the violet is very pale	Dull gilding	1000

Fig. 179 shows the form of muffle used in firing painted and gilded porcelain. The temperature is regulated very carefully, and the watches (montres) are covered both with color and gold, the object being to give a sufficient temperature to fix the gold without altering the tints of the other coloring matters. Painted porcelain is always passed two or three times through the muffle, as it is seldom obtained from the first fire so perfect as not to require retouching.

In Sèvres, a muffle pyrometer is employed, the principle of which depends upon the expansion of a silver rod. The table above, with approximations to the actual temperatures, was taken from the indi-

* Compare gilding glass, p. 144.

Fig. 179.

cations of this pyrometer. As silver melts at 1000° C., the instrument cannot be employed up to that temperature.

An ingenious mode of removing the faults in the paintings previous to re-touching them, has been introduced at the same establishment by Willermet. The part is touched with the end of a brush previously dipped in liquid hydrofluoric acid, and then washed with water. The etched part appears perfectly white, only slightly corroded, and in a very favorable condition for the reception of fresh coloring matter.*

Transparencies.—The translucent nature of porcelain has been made subservient with great success (particularly at Meissen), within the last few years, to the production of very elegant imitations of paintings known as lithophanous (from λιθος, stone; and φαινω, I shine through) pictures or transparencies. When a plate of porcelain, which is thicker in some parts than in others, is held against the light, the former will appear darker, or shaded, as compared with the latter. If both are arranged with judgment according to a model painting, representations of exquisite softness and warmth in the gradations of the tints are obtained. The forming and firing, however, are both attended with very great difficulty. These transparencies can only be viewed by transmitted light; but an attempt has been made to construct some for reflected light, upon the following principle: suppose the dark parts in a porcelain plate deepened, and the light parts in relief, and this plate is now covered with a transparent glass-flux of any color which is sufficiently thick to cover the most prominent parts of the picture, the deep parts will then naturally appear dark, as they will be seen through a thick layer of colored glass, and the prominent parts will appear light.

General Remarks.—It has been previously remarked, that although two descriptions of porcelain may yield the same constituents upon analysis, and the same per centage composition, it does not therefore follow that they will both possess the same properties. A series of observations have been made by Brogniart and Malaguti, with a view to elucidate this point, which have elicited the most interesting relations with reference to the nature of porcelain, and have also furnished important hints connected with its manufacture. Masses were com-

* The most extensive detail concerning the preparation of colors, and the methods of applying them to porcelain and earthenware, will be found in Brogniart's "Traité des Arts Céramique."

posed of different suitable materials, which should afford the same percentage composition as the normal porcelain-mixture adopted during the last 60 years at Sèvres, (namely, 58 silica, 34.5 alumina, 4.5 lime, and 3 potash,) and these were submitted to the different processes of manufacture, in order to study the nature of the result.

When chemically pure substances were taken, such as: 1. Precipitated *silica*, in part fritted with the proper quantity of potash. 2. *Alumina* perfectly free from potash, prepared by precipitation from alum. 3. Pure *lime* instead of chalk; the mass melted at the lowest degree of heat in the kiln to a spotted enamel. Another specimen of the same mixture, only with less frit, shrunk in the warming-oven 18 per cent., in the great fire 28 per cent.

When the kaolin was replaced by fire-clay, and the potash was added, having been specially fritted with silica, a mass was produced, which exhibited, after exposure to the warming fire, the fluxed appearance of ordinary stoneware, and when baked in the great fire could hardly be called porcelain, on account of its slight degree of translucency and spotted nature.

A better result was obtained from a similar mixture of plastic clay, in which a proportion of leucite, corresponding to the necessary amount of potash, was present; a well glazed porcelain was produced, but still somewhat spotted.

On the other hand, no alteration in the properties of the normal mass was observed when lime was employed, instead of chalk, or when the quartz-sand was replaced by flint. It was strikingly proved upon the whole, that it is by no means a matter of indifference, of what materials or of what minerals the elements of the mass are composed, even supposing the relative proportions of the latter to remain unaltered.

Hard Porcelain Furnace.—The porcelain furnace represented in Figs. 180 and 181, has been proposed by M. Vital Roux, of Noirlac, with a view to the consumption of coal as fuel in the manufacture of hard china, without obliging the manufacturer to reconstruct his entire kiln.

The essential difference in this kiln, from the ordinary porcelain-kiln shown in Fig. 170, is the insertion of a grate at *g*, and the air is allowed access to the fuel, from below through the channel *i*, as well as from above *g*, which is its only source in the kiln of ordinary construction. The number of fire-places is increased from 5 or 6 (the number employed with wood), to 8 or 10, according to the size of the kiln. M Roux calls his invention "the kiln with a double draught." He has succeeded perfectly in baking porcelain with coal as fuel. The difference in the expense by employing coal instead of wood is calculated at from £16 to £16 10*s*. for each firing. The ware is said to be better baked in all parts of the kiln, the seggars and the lining of the furnace are less attacked, the draught being very much increased, and the ash of the coal containing a very small proportion of alkali, compared with that of wood, does not vitrify and destroy the clay to such an extent.

Fig. 180 is a vertical section of the kiln, in the direction of the line *C, D.*

Fig. 180.

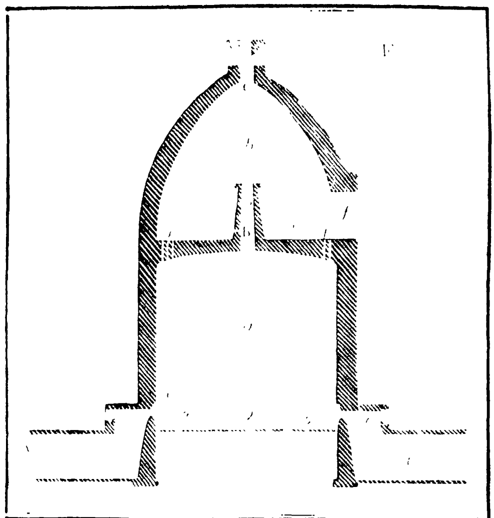
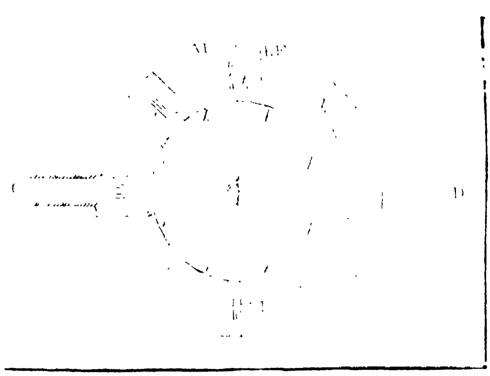


Fig. 181 is a plan, the half of which is taken in the direction of the line *AB*, in the section Fig. 180, and the other half in the direction of the line *EF*. *A* is the lower part of the kiln; *b*, the upper part called "le globe;" *c*, the upper chimney; *d*, the chimney of the

Fig. 181.



lower part projecting into the globe; *e*, the door to the lower chamber; and *f*, the door of the globe; *g*, the openings from the fire places into the kiln; *h*, Fig. 181, small apertures for charging the grates when the lower part of the fire is obstructed; *i*, ash-pits and gallery for the supply of air.

Composition of Hard China.—The following analyses of foreign porcelain have been recently made by Mr. Cowper.

	Berlin.	Chinese.	
		Superior.	Inferior.
Silica - - - - - - - - - - - -	72.96	71.04	68.96
Alumina and protoxide of iron -	24.78	22.46	29.24
Lime - - - - - - - - - - - -	1.04	3.82	1.60
Alkali - - - - - - - - - - - -	1.22	2.68	
	100.00	100.00	99.80
Specific gravity - - - - - - -	2.419	2.314	2.314

2. STONE-WARE.*

The two varieties of clay-wares which are commonly classed together under the above head, differ essentially from each other in the nature of their constituents, and, strictly speaking, the *fine* stone-ware and the *ordinary* are rather two distinct kinds of ware, than species of the same kind. There exist, moreover, such numerous intermediate varieties between the two, that it is hardly possible to make a clear distinction between them.

Material.—The chief raw materials for stone-ware are the layers of pipe-clay and plastic clay which lie above the chalk, and are particularly abundant in the coal formations; or at least deposits of clay, which agree with these in composition and character, although other circumstances tend to class them with potter's-clay. Judging from their behavior towards reagents, the plastic clays, like the varieties of kaolin, must be viewed as definite combinations of silica and alumina (probably $2Al_2O_3,3SiO_3$) with water of hydration, which have been contaminated in a variety of ways with other mineral substances by mechanical agency. A characteristic trait must, however, be noticed, that those mixtures of bases which tend to produce easy fusibility, enter very slightly into their composition, so that the plastic clays in the extreme case are only softened in the furnace, but for the greater part are infusible. The analyses cited at page 206, as well as the numerous investigations carried on at Sèvres, show that these clays contain from 1 to 4 per cent. of oxide of iron, from 0.5 to 2 per cent. of lime, not quite so much magnesia, and from 0.5 to 1 per cent. of potash, although these ingredients are not necessarily all present at once. Their color is generally white, whitish, often gray, passing into greenish, rose-colored, or violet, and in some cases bluish-black or black; it is not unusual to find veins of different colors. At a temperature of 100° C., a portion only of the water which they contain

* The ordinary appellations in commerce of the different kinds of pottery, are so mixed up the one with the other, so misapplied and indefinite, that it is impossible to give a scientific definition of them. Thus, the reader is requested to observe, that the term *stone-ware* is frequently given to two very different substances; the latter of which will be described under the title of *fine earthenware.*

(the hygroscopic water) is expelled; the other portion, which is in chemical combination, and amounts to 6.12 or 18 per cent., can only be expelled at higher temperatures, and completely, at a red heat, at which temperature the clay burns, *i. e.*, loses its plasticity. It is well known that a chemical action occurs at that temperature, the result of which is, that the alumina is rendered much more soluble in acids than was the case with fresh clay. Thus a specimen of fresh clay only parted with 23.4 per cent. of alumina to sulphuric acid; when burnt it lost 44.3 per cent.

The plastic clays in their natural state are pretty free from coarser ingredients and undecomposed fragments of rock, but they contain sand and finely divided silica in very different proportions, whence arises the great discrepancy in the results of the analyses. At Sèvres, where 30 varieties were examined, the per centage amount of silica was found to vary between 42 and 70, of alumina between 20 and 40, of combined water between 6 and 19, the remainder being oxide of iron, lime, &c. The color of plastic clay, after having been burnt, is white, or reddish from the presence of oxide of iron, the other colors, due to organic substances, being destroyed in the fire.

a. FINE STONE-WARE.

The production of fine stone-ware (dry-bodies) is a branch of the potter's art most extensively cultivated, and in greatest perfection in England; in the neighborhood of London the art appears to have been introduced from Holland; the ware known as Wedgwood-ware, on the contrary, which belongs to this class of clay-wares, was the discovery of the celebrated individual of that name, who founded the extensive potteries in the county of Staffordshire, known in England as *The Potteries.**

It is manufactured in great quantity in the most various forms, and attempts were speedily made to imitate it in France (Saargemündt), and Germany (Pirna, on the Elbe). Before the discovery of porcelain, however, Bötticher had already produced a kind of red stone-ware (compare page 212).

The ware, which is called stone-ware in England, is composed of plastic clay, and a flux (a felspathic mineral). The former acquires considerable hardness by burning, but would be very fragile of itself, as it shrinks very much, and is only obtained in the state of semi-fusion, which is characteristic of this ware, by an intense and long-continued heat, which is of course very costly. The addition of flux facilitates this, and acts precisely in the same manner as with hard porcelain; and, indeed, the absence of translucency is the chief external difference between this kind of ware and real porcelain.

* In the course of time, many manufacturers, even on the Continent of Europe, gave the appellation of Wedgwood to their wares, although these were of quite different composition from the genuine article, so that the denomination is no longer to be depended upon in commerce.

Mixture.—The mass is usually composed in England of kaolin, plastic clay and Cornish stone (as flux), but there are no exact statements as to the respective quantities. Sometimes the kaolin, at others the plastic clay, is preponderant in the mixture, but the flux always amounts to nearly the half of the weight of the mass, and is therefore present in much larger proportion than in porcelain. This accounts for the stoneware being completely melted in the porcelain-furnace, or what amounts to the same thing, the heat required for baking this kind of ware is very much less intense than that required for porcelain. It does not follow from this that the mass is less plastic than porcelain-paste; it possesses, on the contrary, the property of plasticity in a very much higher degree, and the plastic clay will bear mixture, in consequence, with a much larger proportion of a poor flux, such as felspar, than kaolin. All these points considered collectively, show that stone-ware is a kind of substitute for porcelain, cheaper in consequence of the greater facility with which it is formed and fired, and having, in common with the latter, the property of resisting the permeation of liquids, but without a similar purity of color and translucency.

Preparation of the mass.—The separate ingredients are ground and mixed with the greatest care, the plasticity being increased by a high state of division. The methods of manufacture, and the apparatus employed are precisely similar to those which are described below, under fine earthenware; this applies to the forming and firing, which can here be passed over, those points being noticed only in which the manipulation is different. The form is given upon the wheel and by turning, when the shape ss t vessels admits of it. Vessels of irregular form are pressed in ager er moulds, as are also the ornamental parts, and the bas-reliefs, w s h are so frequently executed with this kind of ware; these are fixe) w the vessels with much less difficulty than is the case with porce y of w e mass being of so much more binding a character.

These ornaments in relief a base ained like an impression from a seal, by pressure with a concav heir sum mould; the excess of clay is removed with a wire, and the ly so softly pressed with a wet sponge against the moist side of the v ana intended to receive it. The greater portion of stone-ware is carried in mass. It is clear that the coloring metallic oxides must not of pplied in such quantity as to impart easy fusibility, and endang the stability of the ware in the kiln; and none of those must be used whose weak coloring power requires that they should be used in large quantity. A pale green mass is obtained by the addition of $\frac{5}{1000}$, dark green with $\frac{1}{100}$ of oxide of chromium. A blue color is obtained by $\frac{5}{100}$ parts of oxide of cobalt, and with less for pale tints. Plastic clay yields a brown color when $\frac{1}{3}$ of calcined ochre* with about 8 per cent. of peroxide of manganese are substituted for the ordinary flux. A greater addition of both affords an iron-black mass. The masses intended for coloring

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* A mixture of clay with hydrated oxide of iron, the latter being $\frac{1}{4}$ to $\frac{2}{3}$ of the entire weight.

are generally prepared in a different manner from the ordinary ware. In many cases, particularly for blue ware, the mass of the substance is white, and only covered on the surface with a thin-colored coating. As the shrinking properties of the clay are not essentially altered by the addition of small quantities of coloring metallic oxides, an opportunity is thus afforded for applying very elegant ornaments when bas-reliefs are fixed upon a colored ground. The numerous imitations in England of the celebrated Portland vase, white figures upon blue ground, belong to this section.

Glaze.—The largest proportion of the fine stone-ware is not glazed; sometimes a glaze is produced, as it were, spontaneously, which is the case with some colored mixtures. In these cases, the colored surface appears less rough and more shining when removed from the furnace, than those parts which are not colored, and the contrast with the dull ground gives the appearance of a thin glaze. When the vessels are purposely glazed, this may be done in different ways.

In the first place, by a kind of cementation, which is called *smearing*. The inner surface of the seggars is covered with a glaze composed of 67 parts common salt, 28 parts potashes, and 5 parts oxide of lead. During the firing, a portion of the alkali and oxide of lead is volatilized and sucked in by the surface of the vessels, forming a thin layer of glaze. Both the surfaces containing silica endeavor to appropriate a fair proportion of the vitrifiable bases. In other cases, a glaze containing a large quantity of lead or of borax, is applied by the process of dipping, as has been described under porcelain; it is either applied to both or only to one surface of the vessels. By mixing pigments with the glaze, colors may be communicated to the mass which could not otherwise be produced; this is the case with yellow.

All the wares belonging to this class are fired in seggars, often at the same time with earthenware, in the hotter parts of the furnace, or in furnaces that are in no respect differing from those employed for earthenware.*

Utzschneider's Ware.—In Utzschneider's manufactory at Saargemündt, besides the ordinary stone-ware, an invention of the proprietor has been made during the last few years, which has several peculiarities. This is a mass composed of three varieties of clay, which are partly ferruginous and occur on the spot, with quartz, and which produce together a ware exhibiting the most striking resemblance to porphyry or jasper; this is made into vases, the feet of columns, and similar ornamental objects. The body requires the same precautions in grinding, forming, firing, &c., as the fine variety of stone-ware. It is, however, not glazed, but ground, after firing, with emery, and polished with tripoly. The great contraction experienced by this body is remarkable; it amounts to not less than 20 per cent.

Varnished Ware.—It has already been stated that Pirna on the Elbe was one of the chief localities for the manufacture of fine stone-ware, and the productions of this place are of quite a peculiar kind, and

* For further particulars concerning this kind of ware, see Appendix.

stand alone amongst other kinds of pottery; they have latterly enjoyed a very extensive sale. They consist of vessels colored in the body, and excel in the rare perfection and great taste displayed in the selection of their forms, which are chiefly imitations of the antique. The chrome-green and black masses are without glaze, and dull; the bad colored, ochre-yellow mass of other varieties is masked by a coating of often very brilliant colors, which, however, can easily be distinguished from potter's pigments. The soft nature of this coating, its fatty lustre, and destructibility in the fire, which chars it, clearly show that the color is here produced by oil paint. It is particularly obvious with the vessels that have the color of vermilion; these resemble fine sealing-wax. The paint is laid on with great care and very uniformly, without impairing the outlines of the ornaments in relief, and is covered with a thin layer of copal varnish. It perfectly withstands scouring with hot water, but vessels of this kind cannot be used over the fire, or with a knife and fork. Although there may be some exceptions, it may be laid down as a general rule, that fine stone-ware, either with or without glaze, cannot well withstand heat or sudden changes of temperature without cracking, as is also the case with the following kind of ware.

b. ORDINARY STONE-WARE.

Both kinds of stone-ware are consequently wanting in a property which renders porcelain so very valuable. The degree of contraction in this ordinary ware is about the same as in the finer variety, *i. e.* 8 to 10 per cent. One of the principal characters of this ware is the semi-fused state of the mass, which is not a result of the flux that has been added, but of a much stronger heat in the furnace. The composition is much simpler, only one addition being made to the plastic clay; and this not shrinking in the furnace, prevents the clay from contracting to any very injurious extent. Most of the plastic clays possess this property of contraction in such a high degree, that all objects formed from them without this addition, and which are tolerably thick in the sides, infallibly crack in the furnace. Comparative experiments, instituted at Sèvres, are well calculated to show the action of such additions.

The plastic clay of Dreux, mixed

With	Contracts	With	Contracts
10 per cent. coarse cement*	15 per cent.	10 per cent. (ground) sand from Aumont	17 per cent.
25 " " "	5 " "	25 " " "	15 "
10 " (entire) sand from Aumont	18 " "	50 " " "	12 "
25 " " "	15 " "	No addition in nat. state	10 to 11 per cent.
50 " " "	9 " "	" purified by suspension in water	17 per cent.

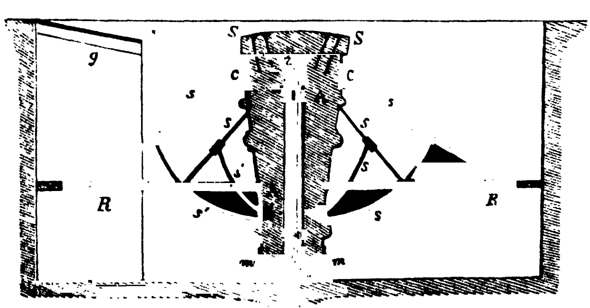
* Ground fragments of stone-ware.

From the last two facts, it appears that the plastic clay under examination contained in the natural state an admixture of some substance that diminished its power of shrinking (sand or fine silica), and which was removed by decanting it from water with an increase of the contractile power. The natural state of the clay must consequently determine the amount of sand or cement that is requisite to be mixed with it. It is a common practice in the potteries, and one of no small importance, to combine a mixture of several kinds of clay (independent of cement or sand) in such a manner as experiment has shown will afford the best result in the fire, both as regards its refractory nature, color, amount of contraction, &c. Other additions than those named, such as alkali or ferruginous matters, are not practicable, as the mass would then lose its stability in the furnace.

In most cases, where vessels for daily use, as stone jars for preserves or pickles, milk pans, mineral water bottles, &c., are required, it would be too costly to decant the clay from water. To remove the coarser impurities, stones, &c., however, which would interfere with the forming of the vessels, the clay is repeatedly kneaded and well trodden together, to render it as homogeneous as possible, and all the larger lumps are separated. In this operation the hands and feet are frequently replaced by the clay-machine, which will be described below. The most simple auxiliary in working up the clay, not only for stone-ware, but for all kinds of pottery, is a wire. The clay is cut into thin slices from a large beaten mass, and these are again rolled together and well kneaded. It is obvious that in this operation, the lumps and stones must sooner or later come in contact with the wire, and the thinner the slices are cut the more frequently this must happen.

Forming.—As the utensils of stone-ware must never exceed a certain moderate price, they are generally made in the simplest forms, and these are such as are circular in section, and can be formed upon the potter's-wheel. The arrangement and mode of operation of this instrument have been already described at p. 226, but there are certain peculiarities in this particular branch of the manufacture, occasioned by the large dimensions of the vessels that are to be moulded. The ordinary machine, Fig. 182, admits of a larger disc or plate being

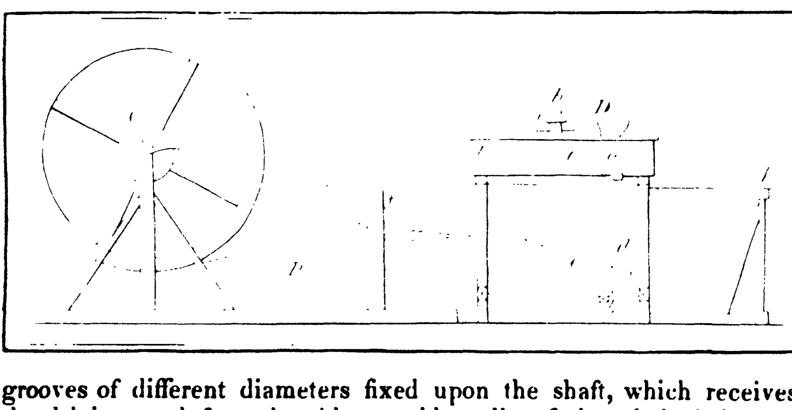
Fig. 182.



used, and a more persistent rotatory motion is combined with the greatest possible facility of revolution. The cast-iron motive balancing wheel *R R*, is connected below the rings *c c'*, which bind the massive hollow axis *A A* together, by means of the double spokes *ss'*, *ss'*. The nave *n* is furnished above with an iron cup *a*, and below with the conical iron shoe *b*. The steel pin *z* works in the former, whilst the iron mouth *m*, in the axis of the wheel, is supported on the latter; these two points are, therefore, the points of rotation of the wheel, which is thus suspended after the fashion of a ship's compass, and is moved with the least possible amount of friction. The disc or plate *S* is nailed to the axis of the wheel, and the whole is depressed for the greater convenience of the workman, who sits on the bench *g*. The disc is set in rotatory motion by an impulse given with a long pointed rod, and this generally lasts long enough to allow the workman sufficient time for one operation. The high degree of plasticity of the mass is a great assistance in this operation, so that the help of an assistant to turn the wheel, is only required under peculiar circumstances of great resistance.

The throwing-machine or potter's-wheel generally used in England, is shown in Fig. 183, and consists of a fixed table *c*, with an upright revolving shaft *a*, *b*; at *a* the disc is fastened, upon which the mass of prepared clay *D*, is moulded by the hands; *d* is a pulley with

Fig. 183.



grooves of different diameters fixed upon the shaft, which receives the driving-cord from the oblong guide-pulley *f*, the whole being set in motion by the fly-wheel *c*, which is turned by a winch-handle *r*. In large works, these machines are all turned by one steam-engine, the velocities being regulated by the driving-belts passing over conical drums: *k* is the seat of the workman, and *e* the foot-board; *h* is the instrument for adjusting the height of the vessels by means of the slide-nut *i*.*

Wide bulging vessels, of small or moderate dimensions, are first

* This machine is sometimes replaced, in the Lambeth potteries, by a large disc, set in motion in the same manner by a cord, and connected with an upright wheel at right angles to the disc, turned by a boy.

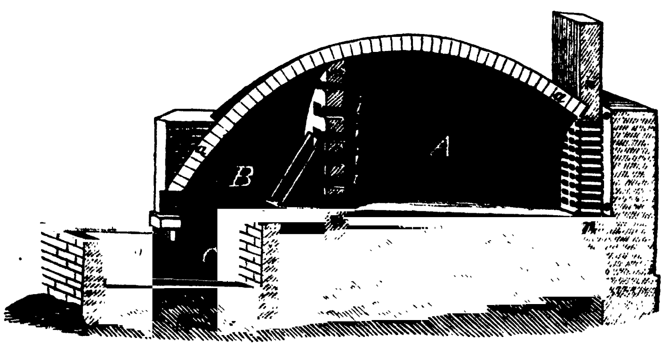
made in the form of a hollow cylinder, of the proper height and width, and the contracted parts are then produced by pressing against the revolving clay. Larger vessels, of similar form, are generally put together from two halves turned expressly. Handles, &c. are made by hand, and simply pressed on to the mass.

Burning.—Upright kilns, such as are used for porcelain, fine stone and earthenware must be of a certain height, in order to economize fuel. As a consequence of this, the vessels are piled up in columns, or bungs, which are so high, that without seggars or some similar supports, the lower vessels would be crushed by the weight of those above them. Supports, however, of this kind, require too much space in the furnace, and too much labor in their construction, to admit of their being used for ordinary stone-ware. For this reason horizontal kilns, or furnaces, in which the draught has a direction more or less parallel with the floor, are used for this kind of ware.

It is only in kilns of this kind that the utensils can be placed alongside of each other, instead of being piled to such a height as places the lower supporting vessels in danger of being crushed. The heat of the furnace is, however, very unequally disseminated when the draught passes in this direction. All common stone-ware is exposed directly to the flame, and as there is no fine surface to be preserved from dirt or scratches, the use of seggars is unnecessary.

The kilns are generally somewhat roughly constructed; Fig. 184

Fig. 184.



represents a section of one of the better kinds in longitudinal perspective, as used at Duingen and Brüninghausen, in Hanover. *A* is the baking-kiln, *B* the hearth, constructed for coal, and which is separated from the ash-pit *C*, by the grate *r*. *A* and *B* are arched over conjointly by an elliptical dome. The draught is regulated through the aperture *g*, by means of a closing plate; it passes through the grate *r*, to the coal, wherever the long flame traverses the apertures *i i*, in the wall *m m*, to the baking-kiln. Here the vessels are fired, and the flame passes out through the apertures in the second wall *n n*, into the flue *o*, which answers the purpose of a chimney. The fire is fed through the stoking-hole *e*; doors in the back wall, and in *n n*, serve

for the introduction and removal of the goods, but they are bricked up during the firing.

Fig. 185 will give an idea of the kind of kiln which is commonly

Fig. 187.

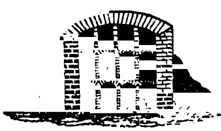


Fig. 185.

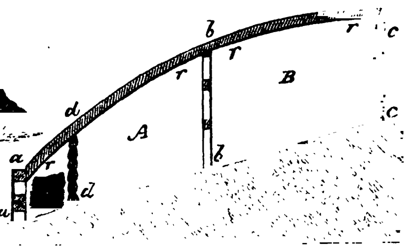
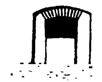


Fig. 186.



used with wood fuel. The sole of the kiln is slanting, that the heat may thoroughly permeate to the bottom, where it is more difficult to burn the goods thoroughly. The wall *a*, with the stoking-holes, Fig. 186, the wall *b* (which divides the baking-kiln into a hinder part *B*, and a front kiln *A*), Fig. 187, as well as the side walls, are all constructed of brick-work; the back wall *c*, on the contrary, the arch *r r*, and the partition *d*, of the fire-place, are constructed of pots made expressly for this purpose. These are particularly applicable for building the arch, as they combine great lightness with considerable stability. The crevices in the arch between the pots are filled up; at *c* and *d*, on the contrary, they are left open for the flame to pass through. When a pot of this kind is equally pressed from all sides, it offers resistance upon the same principle as an arch does upon a large scale. In the hinder kiln *B*, the heat is not sufficiently intense to fire stone-ware; it is consequently used for common pottery. The intermediate wall *b*, is pierced at different places, and is useful in keeping back the ware, which, from the slanting direction of the sole, would otherwise be apt to fall forward.

The warming, or preliminary fire, is continued for five days in this furnace, which is 50 or 60 feet long, and the baking heat three days; the consumption of wood, however, is comparatively greater during the latter period.

The heat often attains 120° Wedgwood, at least in that part of the furnace where the stone-ware is placed, this ware requiring the most intense heat, after porcelain, of any kind of pottery. When the back-wall *c*, has acquired a red heat, the fire is discontinued, and the kiln allowed to cool.

Glaze.—No glaze is properly required for stone-ware, as it is sufficiently dense and vitreous to be impermeable. The somewhat dull surface is, however, made smooth and shining, in consequence of the cheap and simple means by which this can be effected. Any convenient mineral mass is chosen, of the proper composition, which will fuse at the temperature of the baking-kiln. Natural glaze, or the waste from other branches of the manufacture, is ground and sprinkled

or sifted over the moist ware, on which it forms a thin layer, and is then burnt on. Rocks of volcanic origin, lavas, and particularly iron-slag, may be used for this purpose. Berthier found a specimen used in France to consist in 100 parts of: 56 silica, 7 alumina, 21 lime, 1 magnesia, 12 oxide of iron, 3 oxide of manganese—a composition which very nearly corresponds with the formula: $SiO_3,MO+3SiO_3, M_2O_3$, in which M is equal to 1 equiv. of metal. The easy fusibility of the substance is explained by the large proportion of the oxides of iron and manganese which it contains. Glaze of this description is much less frequently used than the very simple and old-fashioned salt-glaze. The process of glazing with salt consists in throwing the salt into the kiln, towards the end of the firing, through particular apertures. It is not necessary that it should be pure; old salt that has been used for preserving, answers the purpose equally well; the process must, however, always be repeated a second time. The volatile salt is converted into vapor at the temperature of the kiln, which very much exceeds a red heat, and this immediately fills the whole interior of the kiln, and consequently completely surrounds the vessels, so that a reaction can take place with the silica of the mass. The two substances (silica and common salt) only act upon each other in the presence of aqueous vapor; this, however, is always present in the flame of the furnace. The oxygen of the water produces soda with the sodium of the common salt, while the hydrogen combines with the chlorine, and is evolved as muriatic acid: $NaCl+HO=NaO+HCl$; the soda then enters into combination with the silica. The glaze thus produced is consequently a soda-glass, and exists as a very thin coating upon the vessels. Leykauf has observed, that the clays which contain more than 50 per cent. of silica decompose salt with so much the more ease the more silica they contain; whilst those which contain less than that amount are without action. A brown color is communicated to the glaze by throwing substances into the fire during the glazing process which afford a large volume of smoke, for instance, the bark of the birch tree. It sometimes happens that the ware becomes covered with salt, a part of which then appears as an efflorescence.

Ordinary stone-ware varies in color from gray to bluish-gray, yellowish-red, sometimes brownish-red or brown; it is, however, seldom so light colored as to be termed white. It is not generally ornamented, with the exception of stripes and rough paintings in zaffre (Cobalt, compare page 121), the outlines of which are traced with a graver or sharp knife.

In Germany.—In the latter half of the 16th and at the beginning of the 17th century, common stone-ware was as much prized as an article of luxury in Germany as porcelain is at the present time. The perfection of the vessels made during that period, the taste and elegance of the forms, the ornaments in relief, and the whole style of the articles, afford an interesting proof of the high state of German art during that period, and of its extensive diffusion amongst the mass of the people. There are at present extensive potteries, where

stone-ware is manufactured, at Bunzlau, in Silesia, and in the neighborhood of Vallendar, on the right bank of the Rhine, opposite Coblentz. In the former locality, the utensils are colored brown by a coating of marly clay, which is applied by dipping, after the manner of glaze. The glaze sometimes contains lead, as is the case with common earthenware. At Coblentz, two kinds of clay are worked, a blue clay for gray ware, and a yellow clay for red.

In England.—The manufacture of stone-ware in moulds has been brought to great perfection in England, particularly the production of vessels for chemical purposes; the smaller vessels for chemical laboratories (basins, retorts, &c.) are remarkable for being thin, light, and well formed; the larger vessels for chemical works (acid bottles, Woulf's bottles, &c.), for their large dimensions. Vessels are constructed to contain from 100 to 300 gallons; their cost, however, may amount to as much as £20. All these vessels are of an agreeable brown color, which is produced by dipping them in water containing oxide of iron in suspension, and are glazed with salt. The clay is brought from Dorsetshire and Devonshire, and is mixed, according to circumstances, with sand, flint, or cement, or worked up by itself, after having stood for a length of time. Heavy and larger pieces are made much thicker than they are intended to be at last, and are turned down to the proper consistence after having been dried in the air. They are fired in upright furnaces, similar to those in use for porcelain, which, in consequence of the high price obtained for the vessels, can be employed in this country. The ware is arranged in the furnace between slabs upon supports, as will be described under earthenware.

The following account of the manufacture of stone-ware, is from Mr. Singer, of the Vauxhall Potteries.

There are three kinds of stone-ware made in England at the present time, viz.:

1st. *Common salt-glazed stone-ware*, made principally in Lambeth, Belper, Nottingham, and Glasgow, but also in many other places.

2d. *Common glazed stone-ware*, coated inside and out with a transparent glass glaze, not produced by salt, and which is made principally at Bristol and Chesterfield.

3d. *Fine compact stone-ware* made in the Staffordshire potteries, which is mostly covered with a smear or flown glaze outside, and a transparent lead glaze on the inside. The first is the original stoneware, and is still the most extensively manufactured of the three.

The following is the method of manufacture, as carried on in Lambeth:

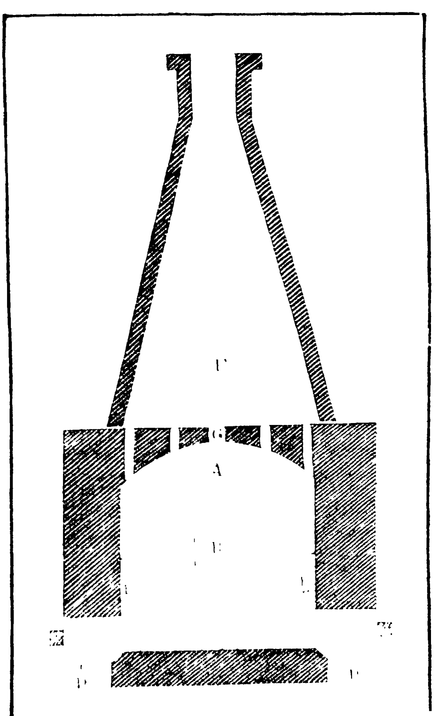
The clay is brought by sea from Teignmouth, in Devonshire, and also from Poole and Wareham, in Dorsetshire. It is cut out of the pits in square lumps of about 40 lbs. each. The Devonshire clay is used for the smaller kinds of ware, such as ink-bottles, ginger-beer and porter bottles, &c., without any admixture whatever, and is, of all the clays in use, that which bakes of the best color in a salt-glaze kiln. The Dorset clays, of which there are a great many varieties, are used for the larger kinds of ware, chemical apparatus, &c.; they mostly become of a much darker color after baking, in consequence

of the larger amount of iron which they contain. Naturally containing very little sand, they cannot well be used without an addition of about ⅟th of sand, or broken stone-ware, ground up and passed through a 16 or 18 hole sieve.

The clay is not washed and boiled, as in Staffordshire, as such a process would be too expensive, besides which, the clay would be rendered more liable to shrink and crack in baking.

The balls of clay are simply dried, broken or scraped to remove any loose dirt adhering to them, and ground to a coarse powder, either under a pair of edge-runners, or a kind of bark mill. When chemical or large common ware is to be made, the proper number of balls of clay to compose the mixture are ground up together, and the sand or ground pottery is added afterwards. There are several modes practiced for mixing this clay-dust with water; it is either put into large tubs, with a certain quantity of water, and the proper amount of sand, &c., and then passed through the pug, or mixing mill; or it is mixed up on a stone floor like mortar, and allowed to remain in a heap for several days, and then put through the pug-mill; or a mill is used to mix the dry clay and water, and pug or grind it at the same time. The method is of little consequence, the only object being to mix the clay and water thoroughly together. After being ground, the clay is allowed to remain as long as is convenient in a damp cellar before being used, which greatly improves its quality. All small round articles are made on a string-wheel, precisely like those used in Staffordshire. Larger articles are generally made on a wheel driven by a pair of mitre-toothed wheels, or by a strap from a shaft driven by the steam-engine.

Fig. 188.



Moulds of plaster of Paris are used for oval, square, or any irregular-shaped vessels, precisely as has been described under earthenware.

Kilns.—The kilns for salt-glazed stone-ware shown in Fig. 188, are usually about 10 feet in diameter in the firing chamber *A*, and 11 feet high to the centre of the crown; they have 5 fire-places, each 12 inches wide and 3 feet long, with 5 or 6 fire-bars *C*, and ash-pit *D*. There is a bag or

chimney-flue *F*, about 5 feet high, opposite each fire. These bags are either made with half-circular thick tiles, pierced with holes about two inches in diameter, or of fire-bricks, with small spaces between the bricks for the fire to escape through. The use of these bags or flues is to disperse the flame in the kiln, and also to render it more intense. There are no flues under the floor of the kiln as in Staffordshire. *B* is the aperture, bricked up during firing, for packing the kilns, and *F* is the chimney. Small articles are placed at the bottom part of the kiln, in square cells, made by stout tiles placed upright, and others laid horizontally on the top of them. These cells or boxes usually extend to one-half the height of the kiln. The whole of the upper half of the kiln is filled with large ware, which requires no support, the lower vessels being sufficiently stout and strong to bear those placed upon them. Previous to being placed in the kiln, most of the goods are glazed inside with a mixture of ground glass and clay, and some of them have the upper part dipped into a mixture of red ochre or calcined copperas and clay, which gives a red brown tint when burnt. There are 20 or more small holes *C*, in the crown of the kiln, through which the salt is introduced when the fire is considered sufficiently intense. (The action of the salt has been before described). Great care and experience are required in the management of the fire. If too little air is admitted to consume the smoke and gas perfectly, the ware will be discolored; and if too much air is allowed to enter with the fire, it will not be sufficiently intense to liquefy the glaze and vitrify the clay.

With a view to ascertain the relative values of plastic clay for the manufacture of fine and common stone-ware, M. Salvetat has submitted several of these productions, of known good quality, to chemical analysis, taking the nature of the glaze with which they were coated into calculation. Five specimens without glaze, and five with different glazes were submitted to analysis with the following results:

GLAZED STONE-WARE, (GRES CERAMES.)

Substances.	Vauxhall.	Helsingborg.	Frechen.	Voisinlieu.	Saint-Amand.
	I.	II.	III.	IV.	V.
Silica	74.00	74.60	64.01	74.30	75.00
Alumina	27.04	19.00	24.50	19.50	22.10
Oxide of iron	2.00	4.25	8.50	3.90	1.00
Lime	0.60	0.62	0.56	0.50	0.25
Magnesia	0.17	traces.	0.92	0.80	traces.
Alkali	1.06	1.30	1.42	0.50	0.84
Loss	0.13	0.23	0.09	0.50	0.81
	100.00	100.00	100.00	100.00	100.00

I. Fine whitish body, well moulded, with a porous external surface, salt glazed.

II. Coarse grayish body, ill moulded, glazed with salt.

III. Dark brown body, fine, well moulded, covered with an earthy glaze.

IV. The manufacture of M. Ziégler, fine whitish body, well moulded, salt glaze.

V. Common body, earthy glaze; formerly analyzed with the same results by M. Berthier.

UNGLAZED STONE-WARE.

Substances.	Saveignies.	China.	Japan.	Baltimore	Wedgwood.
	VI.	VII.	VIII.	IX.	X.
Silica	65.80	62.00	62.04	67.40	66.49
Alumina	27.64	22 00	20.30	29.00	26.00
Oxide of iron	4.25	14.00	15.58	2.00	6.12
Lime	1.12	0.50	1.08	0.60	1.04
Magnesia	0 64	traces.	traces.	0.00	0.15
Alkali	0.24	1.00	traces.	0.60	0.20
Loss	0.31	0.50	1.00	0.40	0.00
	100.00	100.00	100.00	100.00	100.00

VI. Clear brown body, coarse, very sonorous.

VII. Very fine body, well moulded, of a deep brown-red color.

VIII. Body of the same quality as that from China.

IX. Very fine whitish body.

X. Very fine yellowish body, very sonorous, well moulded.

These analyses show that the stone-wares may be divided into two classes; the one, like those in the first table, (with the exception of that from Frechen) comprising 75 per cent. of silicic acid, and the other, like those in the second table, containing only from 62 to 66 per cent of silica.

Some experiments, undertaken with a view to ascertain whether the state of combination of the silica exerted any influence upon the process of glazing with salt, led to the conclusion, that the state in which the silica was combined, appeared to be immaterial, but that an excess of silica in the body was very favorable to the production of a good glaze. The porcelain of Sèvres was hardly glazed at all with salt in some experiments of Messrs. Brongniart and Malaguti.

The salt-glaze applied to stone-ware, does not appear to augment appreciably the amount of alkali in the substance, the clays themselves all containing a certain quantity of alkali.

Salt glazed stone-ware has long been extensively used for the apparatus required for manufacturing muriatic, nitric and oxalic acids, &c. on a large scale, and for jars and bottles to contain acids, spirits, oils, and other penetrating and corrosive liquids. Within the last twelvemonth, it has been employed very largely for drain and chimney pipes of various diameters, for which purpose it is admirably adapted, being perfectly imperishable, impervious, and capable of being highly glazed inside, thus greatly facilitating the necessary flushing and cleansing of the flues and drains.

These pipes are made with a powerful squeezing-machine, similar to that described on a subsequent page, and the cup or socket is

either moulded and stuck on to the pipe, or the pipe is placed in a low throwing-wheel, and the cup is worked up upon it out of the solid clay.

It has also been exclusively used for the insulators for the electric telegraphs on all the railways.

The second variety of stone-ware has not been introduced for more than ten or twelve years into this country, and is still made comparatively on a limited scale at Bristol and elsewhere.

The clay or body is the same as for salt glazed ware; but every article is glazed inside and out in the clay state with a liquid glaze, the materials of which are principally glass and clay, and, as of course, if placed one on the other, as in the salt glaze kiln, the articles would stick together, and be discolored by the fire, they require to be baked in seggars, precisely as earthenware is baked in Staffordshire. The oven used is the same as for salt glazed stone-ware, but of larger dimensions.

This kind of stone-ware is not so highly vitrified as the salt glazed ware, and is therefore not applicable for chemical apparatus, but is used principally for pickle-jars, spirit-bottles, &c.

The third kind of stone-ware has been already described under Staffordshire fine stone-ware.

Mosaic Pavements and inlaid paving Tiles.—One application of this material deserves particular notice, viz: the manufacture of mosaic pavements and inlaid paving tiles. The fine stone bodies being highly vitreous, and capable of being stained throughout of almost any color, are excellently adapted for this purpose. The method of forming the tesseræ is as follows:—The clay being properly prepared and stained of the desired color, as black, red, cane or blue, &c., is made into long, narrow ribbons, by means of a squeezing-machine; these ribbons are cut into squares, which are placed one on another, 15 or 20 high, previously oiled to prevent adhesion.

These piles of slices of clay are then placed under a frame, sliding in two perpendicular grooves, fine steel wires are stretched tightly across the frame, and when the frame is pressed downwards, the fine wires pass through the clay, subdividing the slices into a great number of square, oblong, octagon, triangular, or any other shaped tesseræ required, which are dried, and baked in the ordinary way in seggars.

The mode of forming these colored vitrified tesseræ into mosaic paving-slabs is as follows:—The tesseræ are laid face downwards, on a perfectly flat slate, in the pattern or design required (of course reversed). The size and shape of the slab is given by strips of wood, or slate fastened round the tesseræ. Portland cement is then poured on to the backs of the tesseræ, and two layers of common red tiles are added with more cement, thus forming a perfectly flat and exceedingly strong slab, of any style or color required, and which can be laid down as a pavement, like a slab of stone or marble.

Several varieties of plain and ornamental tiles are now made at Stoke-upon-Trent, by Mr. Minton, upon a plan essentially different from those described above. The coarser kinds for paving streets and

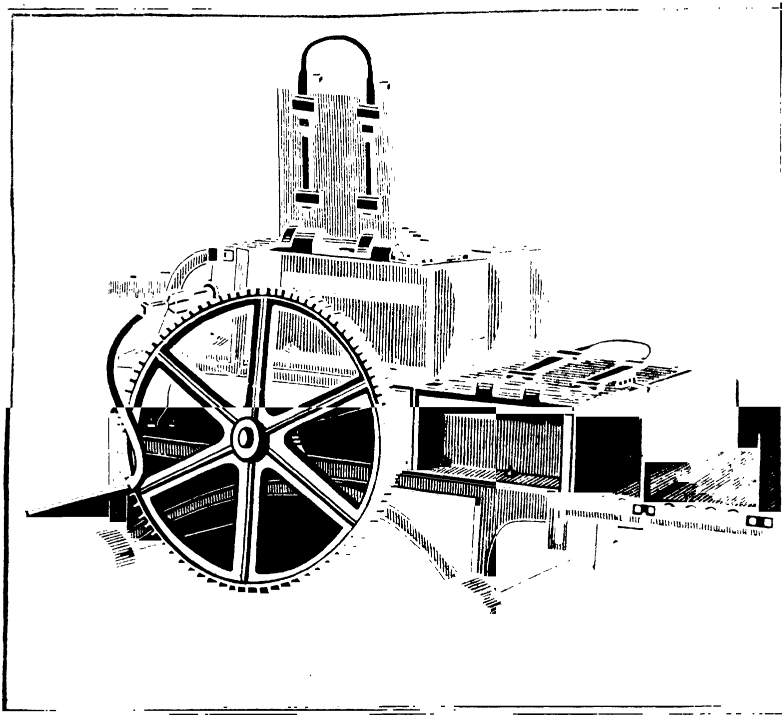
doorways, &c., have a red or buff color, and are prepared from the Staffordshire clay found associated with the coal. By mixing metallic oxides with the finer clays, blue tiles and the finer colors are obtained. After having been prepared, and brought into the state of a fine powder, containing a certain amount of moisture, the clay is submitted to intense pressure under a hydraulic or other press. The powdered clay is placed in a square or oblong iron mould, of the linear dimensions of the tile, which it completely fills, when the ram of the press, which exactly fits the mould, is brought down upon it, with a pressure of from 150 to 250 tons. The clay is compressed into a comparatively very small space, and on being removed from the mould, is polished or smoothed off on the surface by the smooth curvature of a piece of bent tin plate, and is then ready for being baked in the kiln. Tiles formed in this manner, by pressure, are found to contract much less in baking than those that have not been pressed; they contract only $\frac{2}{8}$ths on 6 inches; while under ordinary circumstances, the contraction amounts to $\frac{7}{8}$ths on 6 inches. This is the more surprising, as the specific gravity and power of absorbing moisture of the tiles formed by pressure, and of tiles made in the ordinary manner, is said to be not essentially different.

The tiles are fired in seggars at about the temperature required for biscuit earthenware. The kiln must be slowly heated at first, and the fire gradually increased towards the end.

Variegated or encaustic tiles are also prepared in the same manufactory. For these, a body, composed of ordinary red or buff clay, is pressed in a mould under a common screw-press; the mould not only produces the outer form of the tile, but likewise leaves impressions in the body of the clay about $\frac{1}{4}$th of an inch in depth, to be filled by the different colored clays. On leaving the mould, the tiles are allowed to acquire a certain state of dryness in the air, and the colored material, composed of Devon and Dorset clay, is then poured over the whole surface in the state of a very thick slip; when this again has been dried to a certain extent, the surface is scraped until the face of the original tile, or the common clay, makes its appearance, the cavities only being filled with the colored mixture. A layer of fine clay is also applied to the back of the tiles, and is pierced with holes by projections in the mould, the object of which is to prevent the bending of the tiles in the fire. The finer clay, composing the ornamental part of the tile, not contracting in burning to the same extent as the body of the tile, would cause it to be bent, unless the bending were counteracted by this layer of the same material at the back. The tiles are burnt in seggars in the ordinary manner.

The machine represented in Fig. 189 is one of the newly-invented agricultural tile-machines, which obtained the prize at the late agricultural show at York. The upper box is furnished with machinery for screening the clay and removing the stones. From the lower box, the prepared clay is forced by the machine through the holes in the die plate in front, by which means, tiles of any shape, whether circular, semi-circular, horse-shoe, ridging or flat tiles, can be moulded, and

Fig. 189.



cut off in front of the die plate. The whole machine is placed upon wheels, that it may be easily removed to any convenient spot for preparing the tiles.

3. EARTHENWARE. (FAYENCE.)

Historical.—Amongst the various branches of the potter's art, that of preparing fine earthenware was certainly discovered last, and may be termed modern in comparison with the more common (or enameled) productions.

Clay-wares composed of a soft, porous, calcareous mass, covered with enamel, were first made by the Arabs, and introduced by them into Spain. The celebrated Palace of the Alhambra (built in the year 1273 by Mohamed Ben Alhamar) is profusely decorated with tablets of earthenware, and with urns of the same substance. A knowledge of earthenware was first introduced into Italy by the Arabs (1415); but it appears that the manufacture of pottery was discovered independently by the Florentine sculptor, Lucca della Robbia (1388 to 1430), who cultivated it with great assiduity and success, as a means of embodying artistic conceptions. A grandchild of Lucca carried the art of his ancestor into France, about the year 1530, where

it sunk into oblivion, until it was again revived about the year 1560, by Bernhard de Palissy, who endeavored to imitate the Italian models. About the same time (1520), earthenware vessels were made at Nürnberg, while the celebrated works at Delft in Holland were established in the year 1660. It is, lastly, well authenticated that enameled earthenware was manufactured in Persia in the 17th century.

Specimens of fine French earthenware are said to be in existence dating from the time of Henry II, therefore in the 16th century; but the real starting point of this branch of the manufacture of pottery, for which, from its gradual development, no definite period can be fixed, is much later, and, in its present form, is decidedly of English origin. The use of ground quartz was first introduced by Th. Astbury, in the beginning of the 18th century. He observed that flint became white when calcined, and employed it as a means of bleaching or rendering pottery white. The communication of color to the glaze was introduced by Sadler and Green; the cream-colored ware was discovered by Enoch Wood; but the real founder of the English potteries (1730 to 1795) was the celebrated Josiah Wedgwood. He established, in the year 1770, the village of Etruria, and by his own discoveries, taste, and industry, completely remodeled and greatly extended this branch of industry.

The name *Fayence*, which is given to this kind of ware abroad, is derived from the town of Faënca, in Italy. The older denomination, Majolica, which was applied to Italian earthenware, is believed to be a corruption of the name Majorca, one of the Balearic Islands.

Nature of Earthenware.—Under the term earthenware, a great variety of pottery is embraced, which all possesses an earthy fracture, and is perfectly opaque, is coated with a soft, easily fusible glaze, containing lead or borax; but notwithstanding the possession of these characters in common, the modifications and varieties of this ware are more numerous than those of any other kind. All kinds of earthenware are composed of several species of clay, sometimes plastic or pipe-clay, at others potter's clay and marl, to which quartz is sometimes added. The absence of any real flux, and the fact of its being fired at a temperature which precludes the possibility of the semi or entire fusion of any one of its constituents, distinguishes earthenware from porcelain and stone-ware, while the more careful preparation of the materials, and consequently greater purity of the mass, and in most cases the absence of color, draw a sufficiently marked line between this and common potter's ware. Fine earthenware, as the type of which the English ware may be selected, is composed essentially of a mixture of plastic clay and quartz, and is, therefore, more refractory, harder, and denser than the common ware, the chief ingredients of which are potter's clay and marl, and which is consequently calcareous and soft. Fine earthenware is always coated with a transparent glaze, the commoner kinds with enamel. Both kinds, with some few exceptions, are unfitted for culinary use, as they spiit when exposed to the fire, or the glaze becomes cracked or crased.

a. FINE EARTHENWARE.

Material.—This ware is allied to fine stone-ware, and is generally made in the same manufactory, or at least fired in the same kiln.

The crude materials used in England for the different varieties are: *Cornish stone*, (page 215,) and the so-called *china clay*, a kind of kaolin, which is brought in the decanted state from Cornwall, two varieties of plastic clay, both of which burn white, and chalk flints.

That which is called *iron-stone china*, is made from a mixture of plastic clay and kaolin, with a glaze containing borax; similar ware is made on the Continent, and is known by the name of semi-porcelain (Halb-Porzelan), or opaque porcelain. English *earthenware*, on the contrary, is made simply from plastic clay, with an addition of quartz (flint). Flint, which, whatever its color may originally be, always burns white, acts the part of a bleaching material, or rather as a diluent to render imperceptible the yellow or grayish color of the clay. A third kind, which approaches very closely to common earthenware, contains lime in the form of marl. These are the three principal modifications into which this class of claywares may be subdivided, although there are innumerable others which are of an intermediate character.

The following mixtures are given as examples, and are not to be considered in any other light:

French.		English.					
1.		2.		3.		4.	
Plastic clay from Montereau and Dreux	87	Plastic clay from Dorset or Devonshire	83—86	Plastic clay	64	Plastic clay	82
				Kaolin	16		
Quartz	13	Flint	17—14	Flint	16	Flint	16
				Cornish stone	4	Cornish stone	2

No. 3 is the mass as it is used for pressing; No. 4 affords the *cream-colored* ware so highly prized in England. Very different from these products of the English potteries is that which is called *dry-bodies*, and which has already been described under fine stone-ware.

Body.—The following compositions are used in the English potteries for producing the bodies of the different kinds of earthenware.

CREAM COLOR OR PRINTED WARE.

	I.	II.	III.	IV.	V.
Dorset clay	56	60	66	135*	24†
China clay	27	18	17	19	18
Flint	14	20	17	52	16—17
Cornish granite	3	2		6—7	4

Drab-colored ware is made from the fine gray marl found between the coal strata, which becomes of a cane-color in the kiln; or, a white

* Is employed for cream color, dipped and painted ware.
† Is the body employed for the best printed ware.

body as above is stained with oxide of nickel, or with oxide of manganese, which gives it a greenish drab tint.

Drab body:—

Cane marl	32	or —	or 56	or 26
Drab clay	22	" 43	" 20	" 46
Cornish granite	45	" 50	" 24	" 25
Oxide of nickel	1	" 7	" —	" —
Manganese	—	" —	" —	" 3

Brown, or chocolate bodies, are prepared from the red ferruginous clay of the coal formation, and a variety of tints are produced by the addition of the oxides of iron, umber, bole, &c.

Brown:

Red clay	83	or 60
Dorset clay	13	" 30
Flint	2	" 10
Manganese	2	" —

Egyptian black, for tea-pots, &c.:—

Red clay	45	or 34
Dorset clay	36	" 42
Manganese	13	" 12
Protoxide of iron	6	" 12

Blue bodies, so famous as the ground for the unrivalled cameos and medallions of Mr. Wedgwood, are produced by the addition of a small quantity of oxide of cobalt to a fine white body. When made of vitrescent materials, so as to produce a gem-like surface without glaze, it is called jasper.

Jasper bodies:—

Sulphate of barytes	48	or	Carbonate of barytes	34
China clay	16	"	China clay	15
Dorset clay	24	"	Dorset clay	15
Flint	10	"	Cornish granite	33
Gypsum	2	"	White-lead	3

These mixtures produce a fine white body for ornaments, and are stained blue by the addition of ⅓ per cent. of oxide of cobalt, or green by sesquioxide of chromium.

The *turquoise body* is obtained by adding a mixture of the oxides of cobalt and zinc to a good white body.

The firing of earthenware in the biscuit-kiln occupies three days, *i. e.*, the kiln is fired on Monday and drawn on Friday, and the coal consumed is about 18 tons.

The analysis below, of common white earthenware, is by Mr. Couper.

Alumina and peroxide of iron	68.55
Silica	29.13
Lime	1.24
	98.82
Specific gravity	2.36

Printing Colors.—The colors incorporated with the ink for printed ware are prepared as follows:

Blue color is prepared from oxide of cobalt diluted with flint or carbonate of lime.

Lilac, 2 parts smalt, 1 part manganese.

Brown, zaffre 2, litharge 2, antimony 1, manganese 1.

Red-brown, manganese 12, litharge 2, flint 2, glass 1, borax 1.

Orange, litharge 6, antimony 4, oxide of tin 1, oxide of iron 2.

Pink, equal parts of subchromate of tin and carbonate of lime.

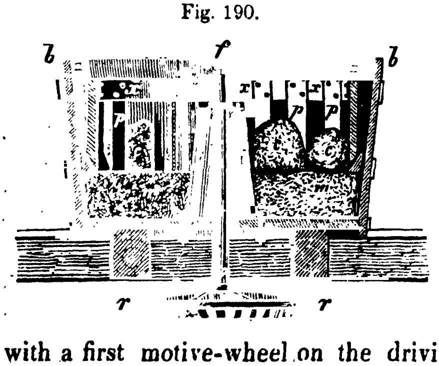
Green, oxide of chromium. The tints are varied with cobalt of zinc.

Black, red lead 60, antimony 25, manganese 15, fritted; then mixed with 40 oxide of cobalt and 5 parts oxide of tin.

In hardening on the color, the kiln is fired until the ware has acquired a bright red heat, which is effected in about six hours.

Flint is an amorphous, black or brown colored mass, composed of silica, which occurs in the chalk in roundish or irregularly shaped nodules, weighing from a few ounces to several pounds. It contains moisture, an organic substance, and sometimes iron. The flints are calcined in upright furnaces, which are kept continually at work, and are similarly constructed to ordinary lime-kilns. The most recent plan of calcining flints, is to expose them in a kiln similarly constructed to the brick-kiln described further on. This plan preserves the flints from all impurities of the coal. The red-hot stones are thrown into water as they leave the furnace. By means of this quenching, the stone is rendered white and disintegrated; it splits in all directions, and is sufficiently soft to admit of grinding. Not only the flint, but also cornish stone, is calcined and ground under water in so-called block-mills, Fig. 190; these mills are universally employed in England. Into a strong vat *b*, *b*, a massive stone block (of chert) *m*, *m*, is inserted as bottom stone, and upon the even surface of this, several loose, heavy stone blocks *c*, *c*, *c*, are caused to revolve by machinery. The mill is set in motion by the wheel *r*, which is in connection with a first motive-wheel on the driving-shaft. The shaft *f* of the wheels passes through the conical box *i*, *i*, which renders stuffing-boxes, &c., unnecessary, nearly to the top of the vat. The one point of rotation of the shaft *f*, is on the outside of the mill, below the wheel *r*, the other is the pan *o*. Above the latter, the shaft enters the nave of a three-spoked wheel *x*, *x*, *x*, and the nave and shaft *f*, can be put out of gear by a peg, and the mill is thus stopped or set in motion. From each of the three arms *x*, (which are let into the fetloc

Fig. 190.

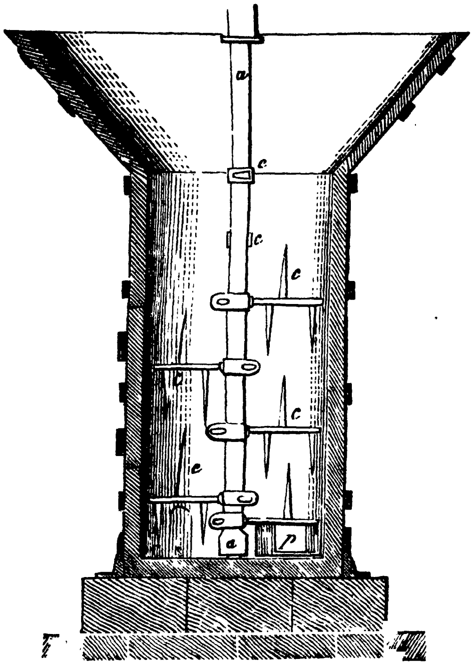


z, as spokes,) the oaken planks *p, p, p,* project perpendicularly downwards, and push the blocks of stone *c, c,* before them, which perform the work of runners. These runners are composed of quartz, a sort of siliceous slate (chert). When these are worn down, or have become too light, they are used for constructing the bottom stone, and the fragments are calcined with the flints and ground up with them.

If the price were not an insurmountable objection, the finest white plastic clay (china clay) would only be used; as a matter of economy, however, this is mixed with as much gray clay as the quality of the ware will admit. In every case the lumps of clay are crushed under upright stones, and then stirred up with water in machines furnished with cross arms, and the liquid with the clay in suspension is then decanted. In this manner a fine aluminous and siliceous mud is obtained, which are each passed separately through sieves, and mixed upon the plan described at page 213. In order to effect a perfect mixture, the two, when mixed, are again repeatedly passed through sieves. The resulting mud, called *slip*, is much too liquid, and must be brought to the proper consistence before any further steps can be taken in the process. This is done by *boiling* in *slip-kilns*, one of the most expensive operations in the whole process, as a large quantity of water has to be evaporated. These slip-kilns are quadrangular troughs of brick-work, from 80 to 100 feet, or more, in length. The fire, which passes under the bottom, (constructed of tiles), is placed at one end, and the chimney at the other, so that the greatest possible use is made of the heat. During the operation of boiling, a dirty scum rises to the surface, and is scooped off; the tumultuous ebullition prevents the particles from separating, and secures a uniform mixture of the ingredients. This drying by evaporation, although expensive, is absolutely necessary, as the quantity of material required is very much greater than is the case with porcelain, and no time can be spared for drying upon slabs of gypsum (by absorption). The fatty nature of the mass also withstands the action of any press, and the water cannot be thus withdrawn; only poor pastes (like porcelain) can be thickened by means of presses, as was described at page 225. In order to be quite sure of the uniform state of the body as regards moisture, consistence and distribution of the ingredients, before it comes into the hands of the moulder, it is usual to pass it through kneading-machines or *pug-mills*.

Clay or Pug-mills.—The action of these clay-mills will be seen by reference to Fig. 191, where *a a a a* is a wooden vat, bound round with iron. A perpendicular cylinder *a*, is placed immediately in the centre of this vat, and is caused to revolve by machinery. Upon this seven horizontal arms are fixed *c c c*, from each of which three sharp blades project. The blades on the lowest arm are connected with each other, and placed in a slanting direction. They are thus enabled to carry the lowest layer of clay forward, and force it out through the aperture *S*. The mass from above constantly sinks, and is brought into contact with all the several blades in its passage

Fig. 191.



downwards. In other machines the blades are fixed in a horizontal position, inclined, however, at a certain angle, so that the whole together act upon the principle of a screw, which, while it cuts up the clay, forces it at the same time down towards the opening *s*.

In the English potteries, the process of weathering the clay and allowing it to moulder is not practiced, but it is worked up at once into vessels.

Moulding.—The makers of earthenware, as of stone-ware, are very much more favored than the porcelain manufacturers, by the greater degree of plasticity of the material. This is not so obvious from the accuracy, elegance, and beauty of the forms, as in the rapidity with which simply rounded vessels can be made. An experienced moulder will make in a working-day of ten hours, assisted by two boys, as many as 60 or 70 dozen plates, or even, according to some statements, many more. A lad and his assistant will make as many as 2000 to 3000 of the small round bottles for containing ink, in a single working-day. This is certainly one of the chief reasons of the low price of the ware. The potter's wheel is here brought into much more extensive use, and is set in motion, in England, by steam.

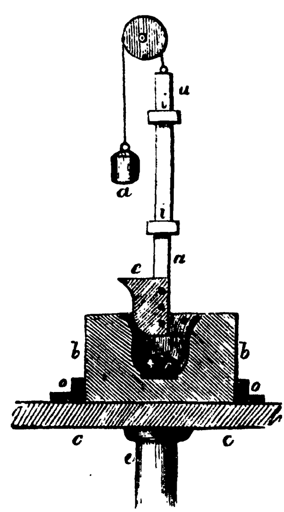
From a common horizontal shaft in the roof of the workshop, a leather belt descends to each separate disc, passing over a conical drum. If the belt works on the narrow end of the drum, the motion is rapid, and may be moderated in proportion as it is advanced to the thicker extremity, so that any degree of rapidity may be obtained. Where steam is not employed, an assistant turns a driving-wheel, which is connected in the same manner with the disc of the throwing-machine (see Fig. 183, page 264). The height and width of the pieces are determined by means of a measure (as was described in connection with Fig. 154). Greater accuracy is not here required, as all rounded vessels of simple form, when they are half dry, are placed in a chuck upon a horizontal lathe, and turned to the proper dimensions. These lathes are generally set in motion by male

or female assistants, who are remarkably apt in adapting the velocity of the motion to the requisitions of the turner, as if the two were impelled by one will only, and, at the same time, they perform all the little necessary operations, such as stamping the goods, bringing and removing them to or from the lathe.

The finished vessels are cut from the disc of the lathe by a wire, to avoid all possibility of bending them. All vessels that are not circular in section, and such as are ornamented with base reliefs, are made in plaster moulds, into which lumps of clay are pressed with sponges (compare page 230). Thin vessels are made at the wheel, with the assistance of plaster moulds and tools. Tools either of metal, horn, or more frequently of glazed clay, are very extensively used, partly for the outer, and partly for the inner surfaces. In many cases, as, for instance, when oval vessels are to be moulded, the plaster mould is fixed upon a *whirler*. The whirler is similar to a common wheel, but the wheel is not connected with any machine to give it a regular motion; it resembles the movable support of the statuary, and enables the workman to place the heavy plaster moulds in any desired position. The bats of clay for plates, slabs, &c., are not made in the same manner as from porcelain-paste, but with the aid of a heavy flat block of gypsum, the ball of clay being flattened by striking it with a peculiar movement upon a smooth table.

An attempt has been recently made in England to replace the hand of the moulder by machinery in cases where certain simple forms are required in great quantities, as, for instance, is the case with cups. The sketch, Fig. 192, is intended to give an idea of this apparatus, without the motive machinery. The cups are moulded by means of the tool *e*, and the plaster mould *b*, the tool forming the interior, and the mould the outer part. The plaster mould is fixed in the proper position by means of the iron ring *o o*, in such a manner that its centre corresponds exactly with the point of the tool. The plate *c*, and the foot *e*, upon which the plaster mould is supported, together form a potter's wheel, which can be rapidly brought into connection with the moving shaft by means of a treadle, and made to revolve. The tool, which is counterpoised by the weight *a*, can also be lowered to the proper distance through the guides *i i*, by means of a second treadle. If a ball of clay *r*, be now placed in the mould, and the treadles are moved, the tool will descend into the revolving mass of clay, and bore a hole (like a boring-machine) forming a cup, the thickness of which will correspond to the distance which the tool, when at the lowest point, is removed from the sides of

Fig. 192.

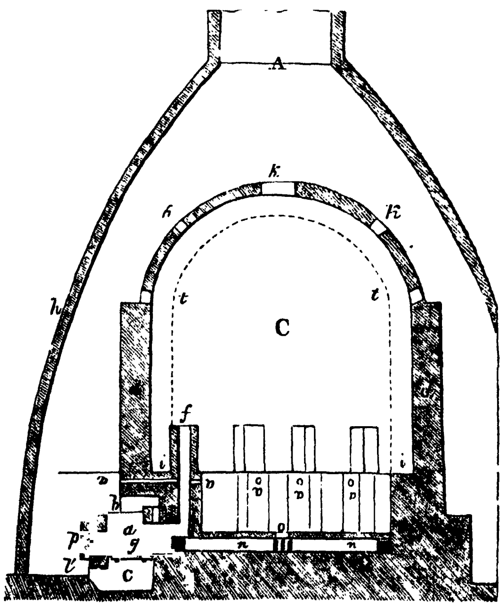


mould. The machine must be regulated so as to secure this proper distance. When the forming is finished, for which a few seconds suffice, the treadles have merely to be set at liberty and the mould comes to a state of rest, the tool being raised up above the mould by the weight of the counterpoise *a*. The mould, with the finished piece, is then exchanged for another, and the same operation is repeated. A machine of this kind can be worked by women, who receive less wages than experienced moulders.

In Mettlach, near Saabrück, the plates of clay are cut out of cylindrical blocks with fine wires by a machine.

Firing.—The temperature at which fine earthenware requires to be baked is very much higher than that which the glaze will bear; for which reason, vessels composed of this substance must always be twice fired. In the first firing, the ware is thoroughly baked or converted into biscuit (which is, of course, a very different state to that of porcelain, after having passed the warming-fire); in the second, the glaze is burnt on. It is usual to employ either two separate furnaces for these distinct operations, or the goods to be glazed are placed in the higher and cooler chambers of the same furnace which is used for biscuit in the lower parts. The former plan alone is adopted in England. The furnace *A*, Fig. 193, which is always surrounded

Fig. 193.



with a conical building, *howel*, *h h*, that answers at once the purpose of roof and chimney, has only one chamber *C*. The construction is the same as that of an upright reverberatory furnace, and differs from the porcelain-kiln in being arranged for the consumption of coal and

a better distribution of the flame. There is an upper aperture *b*, to the fire-hearth, and a lower one *c*, for removing the cinders; *p* is the door for introducing the fuel, &c. It is not absolutely necessary to have a grate *g*, and this is sometimes (in the English potteries generally, entirely omitted. In all cases, however, the draught passes in a downward direction through *b*, and carries the flame in a horizontal direction into the furnace. The flame, however, is divided on entering the chamber of the furnace into two parts, the one of which retaining its original direction, and passing along the horizontal channel *n*, below the sole of the furnace, enters it at the central point, through the opening *o*. The other half of the flame passes through the low chimneys or *bags f*, which are situated at a little distance from the sides of the chamber *d*. Each fire (of which there are 6 or 7) has a corresponding chimney *f*, and a flue *n*; the latter all converge towards *o*, becoming narrower as they approach the centre. The apertures *k k k*, in the dome, allow the flame to escape. In furnaces of an older construction there were no channels *n*, and the bags *f*, were in contact with the sides of the chamber, it having only lately been ascertained that the extension of the diameter of the kiln to the amount of the distance *i*, did not make a perceptible increase in the quantity of fuel consumed. The apertures *v v*, before which are the seggars for the watches, serve for the insertion and removal of the tests, by which the potter judges of the progress of the firing.

The height of the chamber is about 18 feet, and its diameter is 16 feet. The furnaces employed for glazing are of the same construction, but somewhat higher.

As, generally speaking, several kinds of earthenware are prepared at the same time, or fine stone-ware, the rule observed is, to place the goods in positions in the furnace according to the heat which they will bear; thus, for instance, iron-stone china would be placed in the hottest part.

No kind of earthenware can withstand the direct action of the flame, and least of all, the flame from a coal fire, without injury, so that seggars must always be used. The comparatively low temperature, the goods being never heated to the point of fusion, admits of a great economy in the space; the vessels do not require to be so carefully supported, and may be placed much more thickly, one upon the other. It is still necessary, however, to separate the individual pieces from each other. Flat pieces, such as plates, *d*, Fig. 194, merely require triangular pegs *b*, *b'*, *b''*, and *c*, *c'*, *c''*, Fig. 195, composed of clay or hard earthenware. These are fixed in separate holes, purposely made in the sides of the seggars, the plates resting on the edges of the prominent parts. Three pegs thus support one plate with the rim downwards and its bottom towards the upper part of the kiln. Hollow vessels are placed one above the other, or inserted partially one within the other, but are always separated by three-branched pegs, Fig. 196, or others in the form shown in Fig. 197. The seggars are arranged in columns or bungs, 18 or 19

together, and in a furnace of the above dimensions there is room for 87 altogether. When, as is generally the case, 15 or 16 plates can be packed in one seggar, a furnace would then burn (supposing it to contain nothing else) nearly 16,000 plates at once.

Fig. 194.

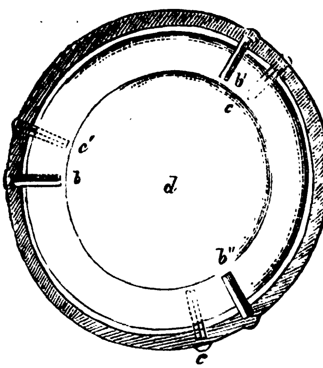


Fig. 195.

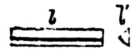


Fig. 196.

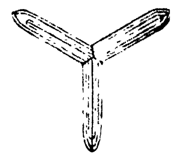


Fig. 197.

The temperature of the biscuit-kiln is 90° to 100° Wdg.

Glaze.—The following substances are employed in greater or lesser quantity as constituents of the glaze:—Felspar, of which considerable quantities are brought from America; this is often replaced by the Cornish stone, already so often mentioned (page 226). Besides these, flint, sand, heavy spar, soda, tinkal (vol. i. page 319), cubic nitre, boracic acid, crystal glass, minium, litharge, white lead (oxide of iron), smalte. The recipes for glaze differ considerably, partly on account of the variable nature of the body, and partly to suit the uses to which the vessels are applied, whether white, printed, or painted; and partly from habit and custom. The glaze, however, always contains lead, and is white; it also contains alumina and soda. The minium and saltpetre exert a purifying action (compare page 31). The oxide of cobalt, of which never more than $\frac{1}{1000}$ is used, is intended to communicate a slight blue tinge to the glaze, so as to hide the yellow color of the body. Good glaze should be very transparent and colorless, should not be easily scratched with the knife, and should be expanded by heat nearly in the same ratio as the body itself. The ingredients are mostly fused together, or sometimes only fritted: the product, when ground and decanted, constitutes the glaze. Melted with boracic acid and soda, it is perfectly transparent and green; with tinkal, on the contrary, it is impure and of a dirty brown color. The minium does not enter into the composition of the frit, but is added by itself to the powdered glaze. The glazing is effected by dipping the biscuit-ware into a vessel containing water and the glaze, made into a thin slip, all the precautions being observed which have been noticed under porcelain (page 236).

The following recipes for glaze are actually in use:

		Cream color glaze.	Printed ware glaze.
*Raw Glazes.**	White lead	66	45
	Cornish granite	22	28
	Flint	12	13
	Flint glass	—	14

Fritted Glaze.	Cornish granite	30	Calcined in the gloss oven in seggars lined with flint, and then mixed with the following:
	Flint	16	
	Red lead	25	
	Soda	12	
	Borax	17	

Frit	26
Cornish granite	15
Flint glass	10
Flint	9
Whitelead	40

The whole is afterwards ground with a little oxide of cobalt to increase the whiteness.

Drab ware glaze, litharge 56, Cornish granite 20, flint 24.

Blue glaze, flint 40, borax 24, red lead 16, Cornish granite 7, soda 5, oxide of tin 5, oxide of cobalt 5. This mixture is calcined and ground with the addition of a little pearl-ash.

Green glaze, 6 pounds of sulphate of copper are dissolved and precipitated by a solution of borax, and then mixed with 10 quarts of white glaze.

Yellow glaze, King's yellow, or chromate of lead is added to white glaze.

Black glaze, red lead 74, flint 14, manganese 10, protoxide of iron 2.

The following are analyses of glaze by Mr. Cowper:

	Analysis of white glaze.	Analysis of frett.
Silica	43.66	55.98
Lime	.52	2.52
Alumina and protoxide of iron	9.56	10.38
Borax	20.08	31.12
Carbonate of lime	10.88	
" " lead	15.19	
	99.89	100.00
Specific gravity		2.345

The gloss- or glaze-kiln is much smaller than the biscuit-kiln, is fired during one day, the consumption of coal being from 3 to 3½ tons.

As soon as the recently glazed wares have become dry, the glaze

* In "raw glazes" the materials are simply ground together in contradistinction to such as are in part fritted, and then mixed with the other ingredients.

is burnt in. The seggars which are used for this purpose, are somewhat larger than the biscuit-seggars, and are glazed on the inner surface, when the danger of the material of the seggars absorbing a portion of the basic ingredients of the glaze, particularly oxide of lead, is to be avoided, in which case the glaze is inevitably rendered rough and dull. The bottom of the seggars is covered with coarsely ground flints, so that the lowest vessels rest upon the sharp points of this angular sand, and, therefore, only touch on few points. The vessels are separated from each other by the same kind of pegs as were employed with the biscuit. The marks where the vessels have rested on the sharp edges of the pegs, may easily be discovered on the earthenware of commerce; the marks are the less perceptible the more sharp the edges were made. The juncture of every two seggars is luted with clay.

Firing.—In firing earthenware, coal is selected which produces a long flame, and it is better when it is not of a caking character, as the fire then requires less frequent clearing, in which operation foreign matters are carried up into the chamber, and the kiln is liable to cool. Large coals are first placed upon the hearth, so as to form a sort of wall or upright grate, through the crevices of which the flame passes. In front of the lumps of coal and above them small coal is placed. The heat is moderated at first until the furnace and its contents have become gradually red-hot, when the heat is increased, and the draught is allowed to enter from below at *b*, while by opening or closing *b* with the lid, the draught is regulated. Biscuit requires 40 hours for firing, and about 15 tons of coal are consumed; the glaze is burnt on in 16 hours. The process is judged of by hollow balls of clay, which are bored through on two sides, and filled with oxide of iron. The contraction and the amount of color produced by the latter, afford a clue to the temperature of the furnace. They are first pale red, and passing through several tints, become at length red-brown. Those varieties of earthenware which are equal to or nearly allied to *iron-stone*, are sufficiently baked when they assume a dark brown-red color; the softer varieties, when the tests appear slightly dark red.

For burning the glaze, balls of clay are used, previously coated with glaze, which assume progressively, the same changes of color, with the heat of the furnace.

It is usual to preserve the trials from the most successful bakings, in order to use them in future operations of the same kind, for the purpose of comparison.

Although it would be inappropriate to expend much art upon the paintings on earthenware, yet this ware is always ornamented (either with a crude sort of painting applied with the brush, or by printing), and is often decorated with metallic lustre on the largest possible scale.

Printing.—The essential principle of the process for printing on earthenware, is the production in the first instance of a printing ink, composed of the finely-pounded color and linseed-oil varnish (just as the color for copper-plate printing is prepared from lamp-black and

linseed-oil varnish), which is printed upon paper in the usual manner.* When an impression of this kind, which is in point of fact a copper-plate, is made to adhere with the printed surface towards the earthenware, and the piece to which it is applied is then immersed in water, the paper and the adhesive matter is softened, and can be drawn or brushed away, while the colored varnish, which is not affected by the water, remains as a drawing upon the vessel, and can then be burnt in. The very same outlines which were first imprinted upon the paper are thus transferred to the earthenware, and burnt in.

Of course, those colors must be chosen, the chemical properties of which are compatible with the circumstances, *i. e.* with the character of the glaze, the temperature of the kiln, &c. Cobalt blue, manganese black, chromium green, are very common colors; but the most admired is the so-called *pink color*, obtained from acid stannate of oxide of chromium with stannate of lime, which is very extensively applied to iron-stone china. This pigment, the manufacture of which was originally a secret, was chemically decomposed by Malaguti, and from the results of the analysis a practical mixture was proposed, which has been prepared with great success in the manufactory at Montereau in France:

The chemical analysis yielded:	
Oxide of tin (SnO_2)	78.31
Lime	14.91
Silica	3.96
Alumina	0.95
Water	0.61
Oxide of chromium	0 52
Chromate of potash	0.26
Potash and loss	0.48
	100.

Hence was deduced the following recipe:	
Oxide of tin	100
Chalk	34
Oxide of chromium	1—1¼ (or
chromate of potash	3 to 4)
Silica	5
Alumina	1

These colors are very seldom printed upon the glaze, but generally upon the biscuit. In this case, the addition of a flux is not always necessary, as the glaze perfectly supplies its place.

The copper-plate is engraved somewhat more coarsely than usual, that the lines may not flow into each other; and the deeper shades, which require more color, are more deeply engraved. The impression, in other respects, is obtained precisely in the same manner as a copper-plate, but is taken upon a particular kind of paper. The paper must be fine, soft, but uniform and durable, like Chinese or tracing paper. In order to render it adhesive, it is saturated with a decoction of linseed or similar gummy substance, [in England with soap,] and brought moist under the press. In this manner vignettes, garlands, bouquets, &c. are imprinted as thickly as possible, with the greatest economy of space, their size being proportioned to that of

* The ink is made of linseed-oil boiled with litharge, resin, balsam of sulphur, or Barbadoes tar.

the utensils. When these figures have been cut off singly with the scissors, they are placed with the printed side upon the biscuit and pressed upon it with wool or with the firmly bound end of a roll of flannel; the vessels are then plunged into water. The paper is easily withdrawn after a short time like a thin skin, and the drawing remains attached to the biscuit with a clear and distinct outline. Accurate impressions, however, will only be obtained when both the surface to be imprinted and the paper bearing the impression, are flat; in most cases the paper has to be applied to a curved surface, with a certain amount of pressure to avoid creases, and this causes a distortion of the drawings. Another very apparent defect occurs in the transference of garlands, &c., ornamental borders; these patterns never run into each other at the juncture of the two ends of the paper, but form at that point a distinctly marked line.

The dry printed biscuit cannot be glazed immediately by dipping as described above, those parts that have become covered with the fatty matter of the color would not absorb water, and no glaze would be deposited upon them. It is, consequently, absolutely necessary to destroy the varnish by heat before the glaze is applied. This process is technically termed *hardening up.* The heat is only required to destroy the varnish, and is not allowed to rise to such a point as would induce a chemical action of the color on the biscuit-ware. A furnace has been recently introduced in England which admits of the most accurate regulation of the heat, and is a great convenience to the manufacture, without involving any expense, as it consumes the waste cinders from the baking-kiln. This furnace is of a quadrangular form, about the size of a moderate room, and arched above. Through a door in the floor an iron box or movable wind-furnace (called a Davy, in honor of the great chemist), is admitted into the middle of the chamber on a railway. In the four corners, pipes project through the arch and descend nearly to the floor of the chamber, which answer the purpose of so many flues to the furnace, and distribute the heat by drawing the flame from the burning cinders to the sides of the chamber. A short pipe is situated in the centre of the roof. This central aperture, and the four others, are furnished with valves on the outside, which are connected with each other by levers, in such a manner that the middle one can only open when all the others are closed, and *vice versâ.* The chamber is now packed as closely as possible with vessels, the Davy and glowing cinders are introduced, the door is luted up, and the valves arranged in the proper manner. The central valve, viz: is kept closed by a rod of lead on the inside of the chamber, the four others are consequently open. The heat increases gradually from below upwards, a dense and very offensive smoke is evolved, until at length the leaden rod can no longer withstand the heat and melts; the central valve immediately springs open, and the four side valves close and stop the draught, the fire is extinguished, whilst the remainder of the smoke escapes through the central aperture. When the chamber has been thoroughly ventilated, the vessels may be removed.

After this operation the glaze may be applied in the usual manner.

When the pattern is applied above the glaze, the surface of the latter must be made receptive of the coloring matter by a layer of copal varnish and oil of turpentine. The varnish of course in this case requires no special process of removal. The transference of copper engravings is occasionally effected by means of plates cast in gelatine. When this is the case, oil varnish, without any coloring matter, is applied to the plate, and the drawing is obtained upon the piece in scarcely perceptible lines of fatty varnish. When finely-powdered coloring matter is now sprinkled over the vessel, the color attaches itself to the adhesive surface of the outline drawing, but not to the other part of the vessel.

Painting.—The application of color by means of a brush and the hand is very little practiced, except for the production of rings and dots, or garlands of leaves or flowers, which are then standard articles, and are made by women expressly kept and taught for the purpose. Thus one will make the skeleton, another the outlines of leaves and flowers, which a third fills up with the coloring matters. The vessels are frequently placed upon the lathe and a ring formed round them by simply holding a brush dipped in color against them while they are in rotatory motion.* Nearly all colors, whether printed or painted by hand, are applied to the biscuit-ware and not upon the glaze.

The ornamental appearance produced by pouring is also differently effected. The substance employed in this instance, is an earthenware paste mixed with coloring matter, and of about the consistence of syrup, which is poured in thin layers over air-dried utensils or biscuit-ware, and which adheres to it after the manner of glaze. This plan is very often adopted in order to produce the appearance of marble. If the marbled appearance is to consist of four colors, for instance, these four mixtures are placed each in separate compartments of a vessel which has only one spout in connection with all four. On pouring from the vessel, all the colors will flow out in a single stream, but unmixed with each other; this stream is allowed to flow upon the vessel to be colored, which is either caused to revolve on the lathe, or is turned with the hand and swung with a certain degree of regularity, so that a waved or marbled appearance is produced. The vessel is then glazed as usual. The pigments in all these cases must be water, and not oil colors.

Lustres.—Gilding is seldom applied to earthenware, but the so-called *metal lustres* are very common. These are exceedingly thin, delicate, brilliant coatings of metal, produced by the application of a diluted solution of the metal and its subsequent reduction. The reduction can be effected by some ingredient of the solution, or, as more recently practiced, by a reducing atmosphere (smoke) in the muffle

* In some places, the color, in the state of thick slip, is blown from a bottle with two spouts (the one of which is furnished with a tube, reaching nearly to the bottom of the bottle or vessel), upon the piece while revolving in the lathe. The rings of color are thus produced, or the whole surface is very rapidly covered with the pigment.

furnace. The lustre sometimes imparts color to the glaze, as well as a metallic coating, and a double effect results. The color in these cases can only be visible on account of the extreme tenuity of the metal. *Gold lustre* produces this effect, and is obtained by dissolving gold and tin in aqua regia, and mixing with it a proper quantity of sulphur balsam (a solution of sulphur in linseed-oil) and oil of turpentine. Platinum lustre is obtained in the same manner, from a mixture of chloride of platinum and oil of turpentine. A lustre resembling that of beetles' wings (Spanish flies) is produced from glass containing a large quantity of lead, to which oxide of bismuth and chloride of silver has been added. When the vessels coated with these preparations are heated to redness, leather, or similar substances, are thrown into the muffle, the products from which reduce the surface of the metal and produce the brilliant coatings, the colors of which vary from green, red, yellow, blue, &c. A lustre of this kind is produced in Spain from copper; the manner in which this is obtained is, however, not known.

The manufacture of earthenware in England is chiefly confined to Staffordshire, to the district called *the Potteries*. In France, it is manufactured in the neighborhood of Paris, at Bordeaux, Saargemünd, &c.; in Germany, at Mettlach, near Saarbrück, Poppelsdorf, near Bonn, (in both of which localities the clay is obtained from Vallendar, near Coblentz, and this clay is imported to Stockholm, in Sweden, for use in the manufacture of earthenware.) Earthenware is also made at Baireuth, Aschaffenburg, Kelsterbach, &c., and at Carlsbad, in Bohemia. In all these manufactories, several kinds of earthenware are produced (as in England) simultaneously with fine earthenware, which form so many transitions from porcelain to fine stone-ware and common pottery. The differences of the manufacture are confined to the methods of preparing the clay, the composition of the glaze, and the ornamental work. Thus, for instance, in Mettlach the clay for the body is only ground, not washed, and simple colored impressions are made with engraved stamps, in the same manner as the letters are stamped at the post-office. Four sorts of fine stoneware are made there, viz.:

1. Stone-ware

from plastic clay from the Palatinate,
ground quartz (from Oberwald or Berncastle),
and a calcareous tufa (from Sierk).

The glaze contains lead, and the ware has a yellow tint.

2. Yellow (nankin-colored) earthenware,

from gray plastic clay from Valendar, near Coblentz, and another kind of clay from the Eifel, which burns yellow. The vessels are coated with lead-glaze.

3. Hard stone-ware,

from plastic clay from the Palatinate,
ground quartz and gypsum (Luxemburg).*

The glaze consists of a tolerably hard lead-glass containing boracic acid.

4. Porcelain stone-ware,

from plastic clay from the Palatinate and from Vallendar, ground quartz and bone-ashes.

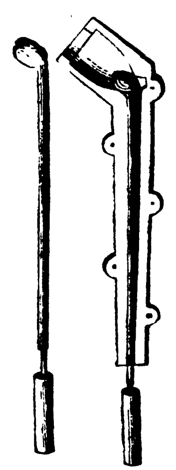
The glaze is free from lead, and is composed of borax, alkali and felspar.

Another very peculiar kind of ware, which will be most properly described in this place, is that composing the

Cologne, or clay-pipes.

The body.—These pipes require a clay that is at the same time very plastic and will burn extremely white and porous; the plastic clay combines these properties, and more particularly, as has been shown by experience, those layers which form the basis of the clay deposits. This clay is used without any addition of quartz or flux, but very great attention is paid to the kneading and slapping, in order to obtain a fine and perfectly uniform mass. This is generally of a gray color previous to burning, and must possess a certain degree of pliability in order to be adapted to the following mechanical operations.

Figs. 198 & 199.



Forming.—A workman first prepares the so-called *rolls*, Fig. 198, two at a time, one in each hand. The thinner portion has rather more than the full thickness of the future tube, whilst the thick part is somewhat less in diameter than the bowl. A second workman receives these rolls in bundles at a time, which are already somewhat dry and stiff; his first object is to bore the tube. With his left hand he forces forward an oiled brass or iron wire fastened to a handle, whilst the thumb and forefinger support the roll, and with a kind of feeling motion, guide the point of the wire.

Fig. 200.

The point is rounded like a button, and the operation is performed much more quickly than would be imagined. At first the whole length of the tube is not bored, but about an inch is left unbored, and the unfinished pipe, with the wire, is placed in the mould, Fig. 199. This mould is placed in a kind of vice, made to fit it, and the part that is to form the bowl is then brought immediately below the pestle or stamp *a*, Fig. 200, so that it is only necessary to put a lever in motion to bring the pestle into the mould, and thus form the hollow of the bowl. It will be seen that care has been taken in constructing the mould to preserve the neat margin of the bowl; and any adhesion of the moulding instruments is prevented by the pipe being oiled whilst passing through the hands of the workman; the bowl is also

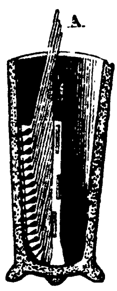
specially oiled. On opening the mould, the tube is completely bored, and the margin is cut straight away with a knife introduced in a slit in the mould, when this has not already been formed by the pestle. This is always done with the pipes that are cut sloping at the bowl, like the English pipes.

When the pipes have been removed from the mould, and the wire has been drawn out, they are laid out to dry until they are no longer flexible; the sutures are removed with a sharp knife, in order that the surface may be polished with another instrument. This instrument is a knife with a semicircular polished blade. When the tube is to be curved instead of straight, it is supported on the drying-boards, at the two ends only, so that it may sink in the middle.

Disposition in the Furnace, and Burning.—The air-dried pipes can only be burnt in seggars, as it is essential that they should preserve their white color. If the pipes are short, and there is no chance of their breaking or bending, as many as possible are thrown into the seggars without any arrangement. If they are longer, ring-formed projections are made round the seggars, upon which the bowls are supported, and a grooved column in the centre, against which the tubes are placed, or the latter alone is erected without any rings, as in Fig. 201. The spaces between the pipes are often filled with burnt clay-powder, or ground seggars, in order that they may be supported on all sides. The ends of the tubes, which project beyond the seggars, are protected by a conical lid. The furnaces are chiefly of the kind represented in Fig. 193, so that they will accommodate a number of seggars at once; they are, however, smaller, and either round or square. In Hanover, they employ very small furnaces without seggars, in which the pipes are protected from the flames of the furnace by means of a lid made of paper, which has been covered with clay. The paper is naturally consumed, and leaves the layer of clay. The firing lasts 14 or 16 hours, and is divided into two periods, during the latter of which the heat is raised to the highest point.

Fig. 201.

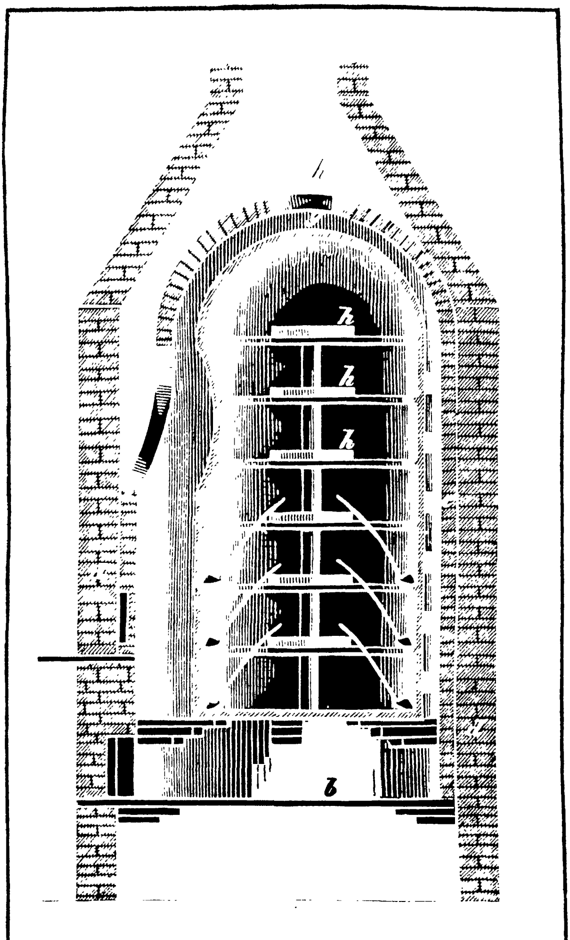
A.



The burnt pipes absorb water with avidity, on account of their porosity, and they consequently adhere in an unpleasant manner to the lips. To deprive them of this property, the points are either rubbed with a mixture of soap, wax, and gum, or they are covered with resin, pitch, or shellac, or, lastly, they are glazed. The glaze contains lead, and is very fusible, so that it is only necessary to hold the covered points for about ten minutes in the flame of the furnace to glaze them perfectly.

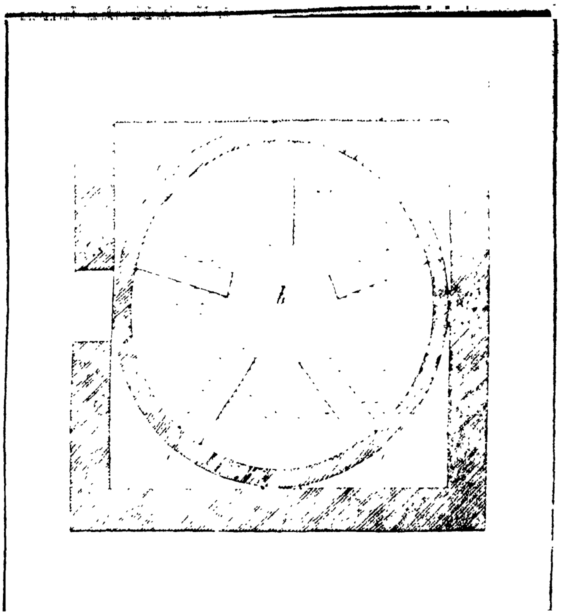
The London tobacco-pipes, which are noted for their superior form, are burnt in a kind of close kiln, seen in section in Fig. 202, and in plan at Fig. 203, from which the flame and smoke of the fire are totally excluded. The kiln-sides and bottom are constructed of the same clay as the pipes themselves, old pipes and fragments being worked up for the purpose; they are built up over the fire-place *b*, a

Fig. 202.



space of several inches being left between the sides of the kiln and the casing of fire bricks *c*, while the whole is enclosed by an outer wall of brickwork *d*.

The fire circulates in the space mentioned above with little interruption, except that which is caused by the numerous supports which are necessary to keep the kiln in its proper position. These supports consist of a number of ribs between the kiln and the fire-brick lining, and which form as many flues. They are perforated with occasional apertures, so as to connect one flue with the adjacent one; but the principal supports of the kiln are five piers formed of bricks, projecting one over the other, the spaces between which form the entrances of the flues. There is an opening on one side of the lining of the kiln, at *c*, which serves for introducing and removing the pipes; this



is closed during firing by an iron door lined with clay. The aperture *h*, conducts the flame to the chimney. The inner kiln-opening itself corresponding with the door *c*, is plastered up with clay and broken fragments of pipes after the kiln has been charged.

In the centre of the kiln a column of clay supports is erected, between which, at different heights, round plates or discs of clay are inserted, and projections are left in the sides of the kiln corresponding to these central plates, against which the pipes are supported, so that the weight of the whole charge is distributed against the sides of the kiln and the central column, and not upon the lowest layer of pipes. The kilns are of various sizes, and will often burn 100 gross of pipes at once.

The fuel used is coke, and the firing lasts from 10 to 14 hours. The heat is slow at first, and gradually raised to the full intensity required for baking. A small aperture is left in the front of the kiln, that the workman may see into the interior, and be able to judge of the temperature.

The red Turkish pipe-bowls more properly belong to common potters'-ware, while the Hungarian bowls consist of a kind of stoneware.

b. COMMON (ENAMELED) EARTHENWARE.

This kind of ware is characterized by its complete opacity, and by being always colored, it is of an open structure, porous, and easily scratched; its fracture is earthy, and, instead of a transparent glaze, it is coated with enamel. It is also chemically characterized by the

effervescence which acids produce with it, and which indicates the presence of undecomposed carbonate of lime in the burnt mass.

Mixture of the Mass.—All the compositions for this kind of earthenware consist of a mixture of:—1, potters' and plastic clay; 2, clay marl; and 3, quartz or sand.

Thus, for instance, the Paris earthenware consists of;

8 parts plastic clay from Arcueil,
36 " of a greenish clay-marl,
28 " of a white calcareous marl,
28 " of a yellowish marly sand.

As a general fact it can only be stated that the proportions and nature of the constituents are very various in different localities; and yet all the recipes agree in prescribing a mean proportion of clay, silica, and carbonate of lime, which will be seen pretty clearly from the tabulated results of the analyses of the earthenware from different localities:

Source of earthenware.	Silica.	Alumina.	Lime.	Magnesia.	Ox. iron.	Carb. acid and loss.	Remarks.
Italian (from Lucca della Robbia) - - -	49.65	15.50	22 40	0.17	3.70	8.58	All effervesce with acids.
Majolica - - -	48.00	17.50	20.12	1.17	3.75	9.46	
Old Spanish - - -	46.04	18.45	17.64	0.87	3 04	13.96	
Manasses, near Valencia	54 71	18 80	19.69	trace	2.20	4.60	
Delft - - - -	49 07	16.19	18.01	0.82	2.82	13.09	
Persian - - - -	48.54	12.05	19.25	0 30	3.14	16.72	
From Rouen - - -	47.96	15.02	20.24	0.44	4.07	12.27	
From Nevers - - -	56.49	19.22	14.96	0.71	2.12	6 50	
From Paris - - -	61.50	12.99	16.24	0.15	3 01	6·10	

The mean of these proportions corresponds very nearly with equal parts of silica, (pipe-) clay and carbonate of lime, which must have been taken as the normal quantities for the mixture.

The analyses also prove that the greater portion of the carbonate of lime has been decomposed by the silica during firing, the carbonic acid contained in the vessels being far too small a quantity to combine with the whole of the lime. This decomposition, however, is never complete, not even after burning in the glaze.

Properties of the Mass.—All kinds of earthenware melt and swell up at a high temperature in the form of a dark brown or green glass, without previously becoming translucent, they are subject, with a few exceptions, as for instance, the brown Parisian ware, to crack when exposed to sudden changes of temperature, which unfits them for culinary vessels. This objectionable property is augmented by a large amount of marl in the mass, and diminished with an increase of clay.

The ingredients are suspended in water, mixed in the wet state and dried on gypsum. The moulding operations are very speedily completed in consequence of the high degree of plasticity of the material. The throwing-wheel, and, subsequently, the horizontal lathe

are the principal instruments used: sometimes, however, plaster moulds are employed, and the processes are precisely similar to those already described.

Firing.—The firing, as was the case with porcelain, is executed in two distinct operations; the first fire is given to the body as a preparatory step to glazing, and the glaze is then burnt in; the difference of temperature in the two fires is, however, but little different, and the last fire is only slightly more intense than the first. Both operations are performed in the same furnace.

Kilns.—The kilns are either horizontal or upright reverberatory furnaces; in the latter case, which is the more general, a moderate temperature only being required, they are heated simply by one fireplace.

Fig. 204 is a perpendicular, Fig. 205 a horizontal section of the

Fig. 204.

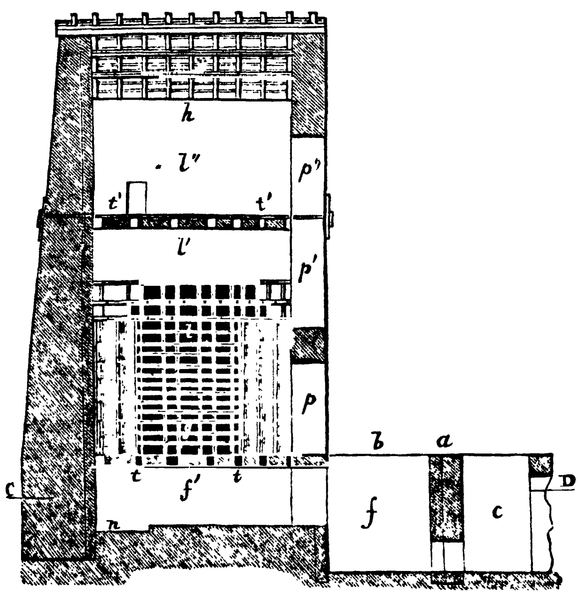
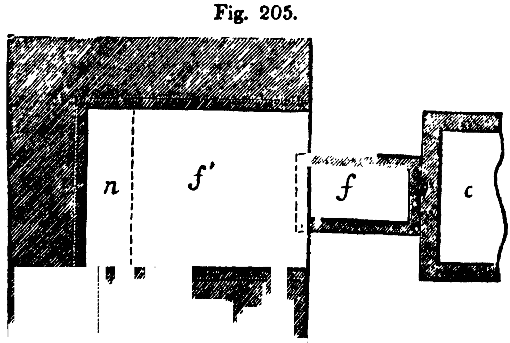


Fig. 205.



kiln, in the direction of the line *C D*. The fire-place, *f*, is constructed for wood fuel, in the manner described at page 240; it is connected with the ash-pit, *c*, at the back, and with the lowest part, *f′*, in the front, the latter being bounded at the top by a low arch. The flame is distributed from thence through the draught-holes, *t*, *t*, into the lowest part, *l*, of the furnace, where the glazed ware is piled up, and from there to the upper region, *l′*, to burn the unglazed ware, which is exposed unprotected to the flames. These latter then escape through the openings, *t′ t′*, of a second arch, either directly into the air, or as is shown in Fig. 204, into a second space, *l″*, which is provided with an open roof. This space *l″*, is intended to preserve the heat for secondary purposes, and to act at the same time as a chimney. The doors, or openings for insertion, *p*, *p′* and *p″*, are bricked up before the firing is commenced. The compartment, *n*, of the space *f′*, is occasionally used for fritting the enamel-glaze.

Insertion of the Vessels.—The better kinds of ware, which require protection from the flames of the furnace, are inserted in seggars, *x*, *x*, Fig. 205, the commoner sorts are supported in a peculiar manner by means of slabs of clay, *y*, *y*. If no adhesion of the glaze were to be feared, the vessels might be piled one upon another without further support, and the slabs of clay would only serve to preserve the layers distinct, and diminish the pressure upon the lower vessels. The angular slabs of clay especially prepared and fired for this purpose are supported on massive clay pillars, and fitting close to each other at their edges, form a connected floor, upon which another similar floor is then erected, and so on. The vessels are arranged between the floors. In order that the flame may have free access to all these compartments, the corners of the slabs are cut out in the form of arcs of a circle, so that on connecting them, round holes are left, which must be exactly above the apertures, *t*, *t*. The biscuit-ware is partly exposed unprotected and piled one piece upon the other, without the intervention of slabs; this is the case with the upper layers in *l′*, but not with the lower layers.

The lower degree of heat in these furnaces is advantageously obtained from hard wood, as that of oak or beech; white ware cannot well be fired with coal as fuel without the protection of seggars. The pieces are separated from each other in the seggars by triangles and pegs. The seggars and slabs of clay must always be glazed for the reasons assigned at page 286.

Firing.—The first fire lasts fifteen or sixteen, the second from twelve to fourteen hours. The temperature in the lower parts of the furnace is about 27° Wg. The body of the ware, the density of which was nearly the same in several specimens (2.363), shrinks from 10, 12, 14, to even 15 per cent., according to its composition.

The glaze is composed of quartz-sand, soda, common salt, and a mixture of calcined tin and lead. The two metals are more oxidizable when mixed, than singly, the oxide of tin (SnO_2) produced, acting the part of an acid to the oxide of lead, (PbO). To prepare this mixture, the lead with about $\frac{1}{4}$th of tin is placed in a special furnace,

where it is exposed to the heat and a current of air. A yellowish ash of tin and lead is gradually formed, which must be calcined for a length of time, in order to oxidize thoroughly all the metallic particles. This metallic ash is mixed with an equal quantity of sand free from iron, about 18 per cent. of soda, 4 to 5 per cent. of common salt, and as much minium, (proportions which are naturally subject to variation in the different localities,) and the whole is fritted in the space *C* of the furnace. When the ash contains a larger proportion of tin, a harder enamel is produced, and *vice versâ*. The usual proportions are about 1 or 2 equivs. of tin to 3 equivs. of lead.

The frit is ground, disseminated through water, and the vessels are covered with it by dipping.

Stove or Dutch Tiles.—The manufacture of vessels from enamelled earthenware has fallen into disuse in the same degree as the different kinds of fine earthenware (stone-ware) have come into more general consumption. This remark, however, does not apply to another application of this material, which is of considerable importance and extent, at least in Germany and France, where it is used for the production of *stove* or *Dutch tiles*. These are composed, as is well known, of slates of enameled clay, of which the porcelain stoves, so esteemed in Northern Germany, are constructed. The difficulties attending the production of this kind of pottery are considerable, and will be best appreciated by a description of the defects to which the common kinds of earthenware in general are subject. The nature and properties of the glaze (enamel) are in no kind of clay-ware so different from the nature of the body as in this common earthenware (fayence), and in no other kind are the two, glaze, and body, so little interfused and incorporated with each other, while the coating of glaze is necessarily thick, in order to hide the color of the material. The addition of carbonate of lime (marl) to the mass, is intended to effect a more firm adhesion of the two substances, (by partially melting into the body of the glaze,) and it does this, although at the expense of the solidity and power of withstanding fire of the ware. In consequence of the dissimilarity of the glaze and the body, their power of expansion by heat being different, common earthenware is more subject than any other kind of pottery to craze or crack as deep as the coating of glaze, becoming as it were covered with a kind of net-work. This, in the case of dishes, &c., enables fluids and the fatty substances of the food to permeate the porous mass below and produce spots, which eventually destroy the utensils, and render them very foul to the smell. When a more substantial glaze is given to the vessels, on the contrary, they are more liable to crack through the entire mass. It is for this reason that these vessels are so badly adapted for household purposes, not being able to withstand the action of hot liquids; in the Dutch tiles, where the mass is often highly colored, and the glaze consequently thicker and more uneven, and which are exposed to sudden and extensive changes of temperature, this defect is much more prominent, and the enamel sometimes peels off completely. The manufacture of tiles, in which both the glaze and the mass shall

withstand the action of heat, is a problem by no means thoroughly solved, and the defect in the tiles is often obliged to be compensated, by lining those parts of the stoves which are exposed to the strongest heat with fire-brick, so as to moderate the heat before it reaches the tiles. The stove-makers are also much restricted in their manufacture by the necessity of avoiding all unnecessary expense.

The body for Dutch tiles generally consists of a mixture of several kinds of clay, to which a certain quantity (about the half) of sand or ground fragments of earthenware is added, as cement. The latter addition is, however, generally too expensive. The ingredients are suspended in water, and the deposited mass is worked in clay-mills, or kneading-machines (*see* Fig. 191), and stored away in cellars. Masses of this kind generally contain very little lime; they do not easily crack, but are subject to the crazing of the glaze. It is customary in some places to prepare the body of the tiles of a coarser material, and to cover the surface with a thinner layer of finer substance before applying the glaze. All the experience that has been collected, particularly that of Pichenot and Barral, tends to show that the mass, and not the glaze, is the cause of the defect, and to correct this, must be the object of future exertions.

Pichenot first endeavored to produce a calcareous body from plastic clay, marl, sand, and ground fragments of biscuit (a body analogous, therefore, to that employed for the vessels themselves), and to prevent the tendency to craze by a very careful kneading process, and in this he succeeded to a certain extent. The burnt material which he employed, contained 56 silica, 28 alumina, 14 lime, and 1 oxide of iron, while the amount of lime in the ordinary mass is only about 1 or 2 per cent. The entire contraction, amounting to 9 per cent., formerly 5 or 6, takes place during drying, and in firing no further contraction occurs.

A mass, like Pichenot's, affords a wavy, somewhat unsightly glaze. Barral has proposed an improvement upon this, which consists in applying a layer of finer material composed of plastic clay, marl, and cement, previously finely sifted. This coating affords a better surface for the glaze, but the tiles nevertheless will not stand the direct action of the fire, and this is chiefly owing to the lime which they contain rendering them more fusible and precluding the possibility of firing them at so high a temperature as is desirable.

If a glass-frit, composed of sand and potashes (or soda), is employed instead of sand alone, very refractory plates are obtained, which, however, become too costly.

The glaze and the mode of applying it are the same as has been described for vessels. In Berlin, white glass is added to the enamel, and any color that is desired, can of course be given to it. Pure white enamel is the most difficult to obtain, marbled is less so.

Very excellent Dutch tiles are made in the manufactory of Feilner, in Berlin.

An ornamental appearance is given to clay slabs and tiles by introducing colored figures upon a uniformly colored ground, without

perceptibly projecting. The figures are first impressed by a kind of stamp or die, and the hollow impressions, when the tiles have been dried, are filled up with a colored material, which is again allowed to dry and is then glazed.

Brown Earthenware.—The brown earthenware of which, for instance, the vessels are composed, in which the Strasburg goose-liver-pies are exported, is of quite a distinct kind. The distinction lies more in the glaze than in the proportions of the ingredients in the body; the glaze is not an enamel but a lead-glass colored to opacity by manganese and iron. A comparison of the proportions used for making the brown Parisian porcelain with those stated above for the white, will show how very similar they are in composition.

The mass composing the brown porcelain is prepared from:		The glaze contains:	
Plastic clay from Arcueil - - - - - -	30	Minium - -	52
Greenish clay marl (from above the gypsum) - -	32	Perox. manganese	7
White marl (from the gypsum formation) - -	10	Brick powder	
Yellow marly sand (from below the gypsum) - -	28	(from red bricks)	41
	100		100

4. ORDINARY POTTER'S-WARE.

Historical.—The potter's art is one of those which obtains the earliest development amongst nations in their transition from an uncivilized state to one of greater culture. The development of the art of pottery is consequently one of the most important points in the history of the civilization of the moderns as well as of the ancients. The fragments and remains of ancient pottery have always furnished the antiquary with a rich source of information of every kind, and been a favorite branch of study. On comparing the productions of the moderns with those of the ancients, the different tendency of the two ages, as regards the technical value of the articles and the amount of taste displayed in their forms, is very striking. While Grecian taste brought the beauty of form to the highest state of excellence, never to be exceeded, the quality of the substance employed, the nature of the ornaments, and the inferiority of the colors, (the knowledge of which was quite in its infancy amongst the ancients,) will not bear comparison with the lowest grade of the art, as it is practiced in the low countries of Europe for the supply of cheap vessels for domestic purposes. These make no pretensions to luxury, and are merely intended for every-day use, no attempts at the more general means of attaining perfection being resorted to.

In a technical point of view, the antique vessels, therefore, belong to the lowest class of potter's-ware, or to the same class as ordinary potter's-ware, and from their great importance, are well worthy a few remarks in this point of view.

It will have been obvious, at a glance, to every one who has visited a museum, that the antique pottery is in reality of two kinds or qualities; viz: the one composed of a coarser, not particularly homogeneous mass, of coarse grain and very porous texture, and generally

composing the vessels of very large dimensions; the other consisting of a very homogeneous, fine and much denser mass, to which the Etruscan vases and the more common vessels of *terra sigillata* belong, which latter are found in all the Roman colonies of Germany, England and France.

Amongst the first class, besides the lachrymal and cinereal urns from the graves of the ancients, belong more particularly the so-called *amphoræ.* These are gigantic vessels, often attaining the height of 8 feet by 3 feet in diameter, with a corresponding thickness in the body.

The body is generally of a light color, but often black, soft, capable of being scratched with the knife, and contains a cement to diminish the amount of contraction. This cement is often quartz-sand; sand composed of calcareous spar has also been observed. In this case, which is exceptional, the mass effervesces with acids. Fragments of similar vessels (which were also known to the Celts) have been found in osseous caverns under conditions and circumstances which refer them to a period very much anterior to the history of Rome or Greece. The barrel of Diogenes was one of these large clay vessels.

The finer varieties of antique earthenware are always colored in the body: some are black, others of a dirty-red or brown-red, others again of a beautiful bright-red color (*terra sigillata*) like red sealing-wax. The body is frequently very fine, *i. e.* prepared from a very pure homogeneous and probably decanted clay. The Roman vessels of *terra sigillata*, so extensively diffused, are of the same color and character in all the localities where they have been found; a circumstance which it is difficult to explain, when the great diversity of the clays is taken into account. The antique vessels are sometimes void of all exterior coating, and are smoothed on the surface previously to being thoroughly dried; or, they are covered less frequently with a layer of a lighter colored material, while the interior is composed of a dark colored clay: sometimes they are coated with a peculiar glaze-like substance; or, lastly, ornamented with black designs upon the surface, which bear the same relation to painted porcelain as drawings in Indian ink to colored paintings. These are either brown upon yellow ground, or black upon bright red, or *vice versâ.*

The numerous analyses which have been made of fragments of Etruscan vases, have yielded from 60 to 69 per cent. silica, 12 to 16 alumina, 7 to 8 oxides of iron and manganese, 2 to 4 lime, and 2 to 3 magnesia, a substance, therefore, which appears to have been formed from ordinary potter's-clay. The color of those specimens which are black throughout is due to 1½ to 3 per cent. of carbon, derived from a smoking fire. These vessels have not all been fired, and when they have been put through that process, the heat employed has not been great; the moulding, on the contrary, which has obviously been performed upon the potter's-wheel, is very perfect, and figures in relief, obtained from clay moulds, are also of frequent occurrence. The vessels prepared from *terra sigillata* are not strikingly different from the others in chemical composition, but are subject to greater

variation amongst themselves. They contain more oxide of iron, as much as 12½ per cent., which accounts for their red color. The glaze-like surface of these red vessels is very little colored, it is remarkably thin, transparent, and composed of 64 silica, with 11 oxide of iron, and 20 soda. The black glaze is of very similar composition. It is quite impossible to specify whether these were obtained by means of salt or otherwise. The white castings which are sometimes met with upon red vessels consist of pure clay, containing no lime or magnesia, but a little iron. Designs in relief were also produced by castings, in a similar manner to the marbling (page 289), but of course with one color only.

The coating of glaze upon the vessels, as they are met with in Magna Græcia, is a vitreous compound, containing a large quantity of iron, which resists the action of acids and caustic alkalies, but is readily dissolved by fusing with potash; small splinters of the substance are not in the least attracted by the magnet. The black color of this thin layer of glaze, which is very common, as well as the designs produced upon a light ground, are derived, according to Salvetat, from iron and manganese, and can be imitated.

Ordinary potter's-ware, such as is now everywhere produced, although it shares the technical character of the antique pottery, is destined to serve a very different purpose. The baser kinds of this ware are intended to afford the less wealthy classes with *cheap* utensils that are *impervious to liquids*, and will *bear changes of temperature*, so as to be suited for boiling, and which can be manufactured in all localities. The latter point implies the use of very different kinds of clay, and more especially such as can be obtained at the least expense; hence the extensive use of potter's-clay, marl, &c. The price, moreover, will not admit of expensive methods of moulding, nor of the better arrangement of the firing-kilns. Here, as in other similar cases, an ill-understood economy is the mother of extravagance; under present circumstances, common pottery is manufactured by a number of persons who are generally without the means and opportunities of introducing improvements, even if they knew how to benefit by them. The waste of fuel in badly-constructed kilns is a great source of loss, and is to be attributed to these circumstances. The greater number of the varieties of clay which are worked, will not withstand a high temperature, even if this could be procured at a sufficiently cheap rate. The baser kinds of pottery are, therefore, generally fired at a low temperature (and this distinguishes them from stone-ware), which renders them porous and of low density, and obliges the manufacturer to coat them with a glaze. This glaze must necessarily be burnt on at a temperature which is insufficient to cause the fusion of the mass; it is, therefore, generally a lead-glass, or a very easily fusible earthy glass. No reason existing for concealing the color of the mass (which is dirty-red, or yellowish, sometimes brown or grayish, seldom white), the glaze is always transparent, and may be either colored or not, as required.

The crude paintings and doggerel rhymes with which ordinary pot-

ter's-ware is decorated, are produced by glazes of different colors, (one of which forms the ground, and the other the design or the letters.) The low state of public taste, and partly the entire want of it, are exhibited very prominently in modern pottery, which in itself is capable of much greater perfection in point of beauty. Meritorious exceptions, however, are met with, as at Marburg, where the brown-colored vessels are neatly ornamented with designs of flowers that appear to advantage through the light yellow glaze.

Body.—The preparation of the clay is confined to two operations. The first consists in mixing it with the necessary quantity of water, and allowing these two to remain for some time together, during which the clay is frequently turned over and stirred, that the action of the water may be uniform. It is then submitted to the operation of *blunging*, or is beaten up into lumps, which, in order to remove knots, stones, &c., is worked up two or three times with the aid of a knife or wire, as described, more minutely, at page 263. Clay of good quality should be easily worked on the throwing-machine, but must not shrink so much in the kiln as to cause cracks, and must "carry" the glaze, *i. e.*, the glaze must be chemically constituted, so as not to melt down with the body, or be absorbed by it. These properties cannot be previously determined, and are all matters for experience; the potters are in the habit of ensuring success by mixing different qualities of clay with each other. The addition of sand to diminish contraction is not unfrequent when the clay is too fat.

Glaze.—Ordinary potter's-glaze is an aluminous lead-glass, prepared from litharge or galena,* (glaze-ore.) The substances containing the lead are finely pulverized in the glaze-mill, and mixed in proper proportions with loam, or for colorless glaze, with sand. The glaze-mills are hand-mills, similar to grain-mills, with two stones lying one over the other, which should be of quartz-rock. The potters generally buy the glaze ready prepared. Metallic oxides are used as pigments, as far as their price will admit; *zaffre* produces blue; *oxide of copper*, green; *red antimony ore* (sulphuret), yellow; *manganese*, brown and black, and *iron*, red, &c

The glaze is applied: 1. By *dipping*, in which case the ware must have been previously fired, and this renders the plan too expensive; 2. By *casting*, or coating with a thick pasty glaze, the cheapest and best plan; 3. By sprinkling the moist vessels with the glaze in powder. The two latter modes are commonly practiced, but sprinkling the powder is a dangerous operation for the lungs of the workmen. It is not usual to pay attention to any definite proportion between the amounts of oxide of lead and silica in the glaze, or as to whether they are in combination or not. Proportions that have been tried, are taken, as for instance, 7 parts litharge to 3 or 4 of loam, which are very variable, and it is presumed that sufficient time will be allowed the oxide of lead in the furnace to become fully saturated with silica.

* This forms oxide of lead and lead salts (sulphite of lead, &c.) in the furnace, which are then decomposed, and the oxide of lead combines with the silica.

Thus, in Darmstadt, four comparative experiments were instituted, which clearly show, that when the heat has been sufficiently intense, all the lead enters into combination. Out of 12 vessels specially marked by the potters,

The "too hard fired"	gave	no indications of lead,
" "hard burnt"	"	no indications of lead,
" "well burnt"	"	in some cases indications of lead, in others none,
" "ill burnt"	"	in every case indications of lead,

when digested for some time in distilled vinegar. Acid liquids, therefore, dissolve the oxide of lead, which is uncombined or only in weak combination, and this is only the case in badly-baked vessels, and then only on the first application of the acid. The amount of lead dissolved, however, is very small, although some time ago a great outcry was raised against the danger attending the application of lead-glaze, which apprehensions were totally unfounded, as endemical diseases must have shown themselves long since if they could have been engendered by the extensively-used lead-glaze, and this cannot be proved to be the case. Glazes, free from lead, have been proposed, and it has been overlooked that these have been in use for many years in some places. Thus, the brothers Hardtmuth, in Vienna, have long used a glaze consisting of 100 lbs. borax, 50 lbs. felspar, and 50 lbs. loam, which would answer every purpose, if it were not too expensive. Ordinary potash or soda-glass, with or without an earthy admixture, have been proposed by Feilner and Niesman, but are either too dear or too difficultly fusible. Siebel recommended Fuchs's soluble glass, with the addition of lime; but it was not found suitable. In Bischoffswerda, Pulznitz, and Camanz, in Saxony, the glaze is composed of an easily-fusible potter's-clay which is found there. In Kirchenlamitz (Bavaria), on the other hand, where an excellent material is produced, that withstands the change of temperature almost as well as crucible-ware, and whence the Saxon princedoms, northern Bavaria, Reuss, &c., are supplied, the glaze consists of the slag from the smelting-furnaces. This substance is transparent, full of air-bubbles, harder than glass, and gives sparks when struck with steel; its color is either bottle-green, light or dark blue, passing into green. Both kinds are not acted on by acids. Reinsch, who supplies this information, found it to consist of:

		Oxygen.	
Silica	65.00		33.70 in the silica.
Lime	12.35	3.53	7.37 in the bases MO.
Magnesia	2.56	0.99	
Potash	2.00	0.34	
Protoxide of iron	5.00	1.50	
Alumina	8.00	3.73	5.06 in the bases M_2O_3.
Oxide of manganese	4.45	1.33	
	99.36		

which corresponds very nearly with the formula $4(MO,SiO_3)+(M_2O_3, 3SiO_3)$ and is consequently not identical with bottle-glass, to which, however, it is nearly allied. The slag is pounded in granite mortars, then ground with water under the glaze-mills, and applied by pouring it over the vessels, which have been previously covered, by immersion, on the outside with a thin coating of loam, that they may acquire a red-brown color. After firing, the ware has a dark yellow tint, and is free from bubbles; this substance is mixed with more or less lead-glaze upon those vessels which are placed in the cooler parts of the kiln. The high melting-point of this slag is an objection to its general introduction, but this was of no consequence in the case described by Reinsch, with the pottery of Lamitz, which is extremely refractory.

Kilns.—Ordinary potter's-kilns are very long, horizontal, reverberatory furnaces with one fire-place; or horizontal, slightly inclined, in cross section, very capacious channels (7 or 8 feet high, and from 20 to 30 feet long), which are traversed lengthwise by the flame, the fire-place being at the one end, and the chimney at the other, where the aperture for introducing the ware is also situated. The fire-place is separated from the baking kiln by a pierced wall (*Ständer*) (similar to the wall *r*, Fig. 185), and the whole is covered by a so-called barrel arch. The dimensions of the kiln and the cross sections are very variable in different localities. Thus, for instance, the sole of the kiln in Kirchenlamitz is not rectangular, but egg-shaped, 16 feet long, 5¾ feet wide, the height in the middle is 4½ feet, at the further end 4 feet. The cross section is belly-shaped, so that the width of the sole, which is 5¾ feet, is extended to 6¾ feet. The height of the mouth of the chimney from the sole of the furnace is 20 feet. A kiln of these dimensions will contain about 1000 pots of 4, 6, and 8 measures (*Maass*) capacity, when the smaller ones are placed inside the larger, which is the usual practice. The temperature diminishes rapidly towards the chimney, which must not be overlooked in packing the kiln. In the front, or hottest part, the vessels are placed upon supports of 1 foot in height; further on, they are set upon the sole of the kiln, which is strewn with sand. The vessels that are placed in the hindermost parts of the kiln are also covered with a more easily fusible glaze, for instance, lead-glaze, while those in the front are covered with pure slag, and the middle vessels with a mixture of the two. All the vessels are exposed unprotected to the flames, but precautions are taken to prevent them from touching each other, that the glaze may not cause them to adhere too firmly together. A baking lasts twelve hours in one of the kilns as described at Lamitz, and consumes 2 stacks of pine-wood cleft into billets 3½ feet long, the half of which, however, may be considered as wasted. Further description and illustration of ordinary potter's-kilns is unnecessary, as these common wares are frequently baked in the same kilns with stone-ware and bricks. We refer, therefore, to what will be described hereafter upon this subject, and more particularly to the description of Henschel's brick-kiln.

A throwing-machine, similar to that shown in Fig. 153, but generally of much cruder construction, is employed for moulding the vessels. With the exception of the measuring-rule, no instruments are employed in the operation. The application of glaze to this ware is in many cases inadmissible; for instance, for flower-pots, sugar-moulds, &c.; in others it is omitted in consequence of the difficulties attending it. This is the case with the vessels so remarkable in their dimensions, which were used in ancient times, instead of wooden barrels, for storing oil, wine, &c. (already noticed under the name of *amphoræ*), and which are still used for the same purposes in the south of Europe, in the East, and in America. The French call them *jarres;* the Spaniards, *tinajars;* the Italians, *orcia;* and the Armenians, *koupchines.* They are known to the Hottentots in Africa, also in Java and in the Brazils. They weigh as much as 4 cwts., and hold from 600 to 1,900 lbs. of liquid, as much as 6 Ohm (=about 180 gallons) therefore. The mass of which they are composed is coarsely granular, and consists of a mixture of potter's-clay and sand. The moulding is performed simply with the hand, and the sides are built up with long ridges of clay, which lie one upon the other, like rings, or are intertwined in a spiral manner. Both surfaces, the inner and the outer, are then smoothed, and the handles and ornaments are fixed on. The firing is effected in kilns which are constructed to contain about 40 pieces.

Coolers.—Cooling-jars and vessels form a good illustration of the use that is made of the porous nature of unglazed clay. They are used in hot countries for holding water, and retaining it at a temperature several degrees below the surrounding atmosphere. The water permeating the vessels through the pores, arrives at the outer surface, and evaporates with great rapidity in consequence of being spread out in a very thin layer. The considerable amount of heat, therefore, which water absorbs in evaporating, is rapidly removed from the surrounding objects, or in this case, from the cooler with the remainder of the water. The temperature in the interior must, therefore, be lowered, and this will continue as long as water remains in the vessel and permeates the sides. The cooling, however, does not amount to so much as is generally stated; thus, at Sèvres, where the temperature of water in an ordinary vessel was compared for experiment with that in a suspended cooler, it was found that the latter was 3°, and at most 5° below the former; this difference would of course be greater if the temperature of the water were compared with that of the air. The difference in southern climates may possibly amount to twice as much.

In South America these vessels are called *canaris;* in Egypt, *quolleh* or *bardach;* in Spain, *bucaros alcarazzas.* The porosity is increased by giving only a slight degree of heat in the kiln, and by the admixture of substances which are destroyed in the fire, and leave minute pores in the mass. Common salt may also be mixed with the clay, and subsequently be dissolved out with water.

It frequently happens that a very large demand for particular

articles of this class of wares is created in certain localities, and their production is then carried on upon a manufacturing scale with care and attention, as the case may demand. In illustration of the processes then adopted, it will be better to confine our attention to a single instance, and a concise description of the manufacture of clay pipes for conveying water, &c., as carried on at the manufactory of Reichenecker, at Ollweiler, in Alsace, will answer our purpose.

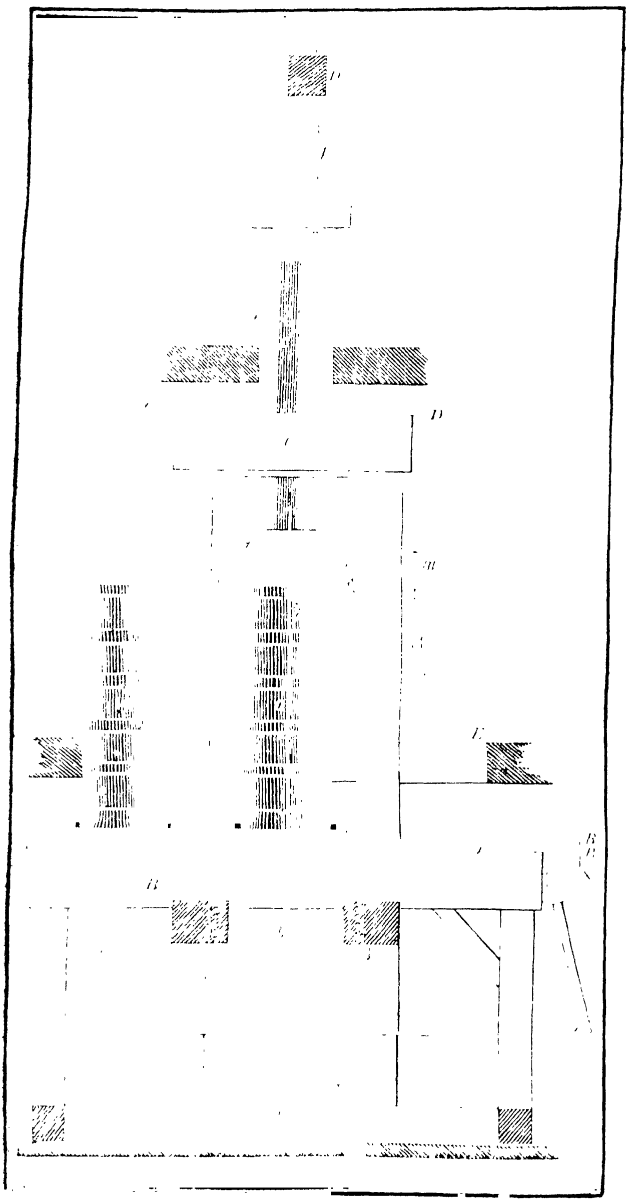
CLAY PIPES OR TUBES.

The material employed for these pipes is a pure plastic clay, which is always mixed with another of a less pure nature, containing oxide of iron, sand and mica, in certain proportions which it is essential to observe. Ground fragments are always added to the mixture. These latter are crushed under stampers, and the crude clay, when too dry, is treated in the same manner, and brought in the finely crushed state into a cistern, in which, by means of a stirring-machine, it is agitated until it forms a thin slip, which is then allowed to pass through a revolving cylindrical sieve. The coarser particles remain in the cylinder, and fall through into a separate vessel, while the pure clay passes through the wire meshes into the settling-pit where it is deposited; the water is then drawn off, and the clay paste is conveyed to the mixing-pits, which are lined with planks, are situated side by side, and in connection with the kneading-machines between them. The different ingredients having been softened with water and mixed in the front pit, the compound clay-mixture is passed through the kneading-machine into the second, or storing-pit. The kneading-machine consists of two cylinders, which revolve with different velocities, (and consequently exert a tearing action), the distance between them being regulated by two screws. A wooden hopper, or funnel, conducts the mass of clay between the rollers. The clay being thus thoroughly kneaded, is in a proper state for moulding, and this is effected by setting a powerful hydraulic press in action. The object of this instrument is not merely to mould the pipes from the soft clay, but more particularly to increase the density of the material by pressure, and thus ensure the durability which is required to withstand constant pressure and the action of liquids. In order to bring the separate particles of the mass into the proper degree of proximity, it is not sufficient to exert a powerful pressure, unless the clay possesses precisely the proper degree of dryness, which is difficult of attainment. When the interstices of the clay are completely filled with water, this very inelastic liquid, retained in its place by capillary attraction, resists most pertinaciously the action of the press; and when the clay is over dry, the moulding becomes too difficult. To secure the proper mean between these two extremes and retain a uniform state of moisture throughout the clay, it is usual to place the half-dried balls, of about 8 inches in diameter, upon a smooth stone, and beat them into the form of a flat cake, that no moist nucleus may

remain in the interior while the outer surface becomes dry. These cakes are then cut in half, horizontally, and again beaten together with the inner surface exposed.

The process of moulding with the hydraulic press is kept a secret

Fig. 206.



at the manufactory; but a similar process will be described below, under the head of fire-proof clay-wares.

The following are the description and drawings of Reichenecker's machine:

The machine consists 1st, of a hydraulic press, attached to framework, and which exercises a downward pressure; 2d, of two hollow cast-iron cylinders, fixed near each other in a movable frame or cradle, so that they can be brought alternately under the ram of the press. The material which is to be manufactured, is placed in the cylinders, and as it is subjected to a very strong pressure, these must be carefully bored. The moulds for the pipes are attached to the lower end of the cylinders; 3d, of a number of conical moulds, which pass into the cylinder from below, and which can be changed according to the nature of the article to be manufactured. The materials are forced and drawn through these forms, and made into tubes or any other articles, which may be cut to any desired length by an iron wire. The drawings represent the machine in various positions, as it is used in making water-pipes.

Fig. 207.

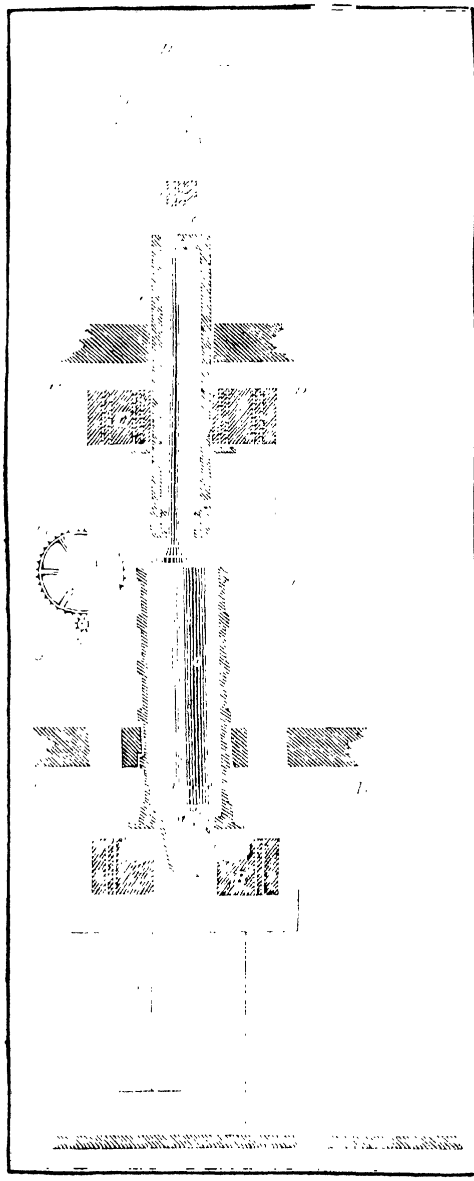


Fig. 206 is the elevation of the entire machine. Fig. 207 is a vertical section of the same. *A* represents the framing; *B* the cross-beam upon which the movable cradle rests; *C D* are the upper cross-beams; *a* is a double pump for the hydraulic press, which is always kept supplied with wa-

ter; *b*, a copper pipe for conveying the water to the cylinder; *c*, the working-cylinder; *d*, an opening for admitting the air at pleasure, which is made tight by means of a screw; *e*, ram of the press, which passes into *o*; *f f*, rods which are attached to the ram for the purpose of raising it after each operation: these rods pass through the cross-piece *g*, to the upper side of which they are bolted by screws. A block *h*, is fixed to the middle of the cross-piece, in which there is a pulley *i*, and the rope round this pulley has a hook *j*, at one end. The rope passes over another pulley *k*, which is fixed in the cross-piece *D*, and winds round a drum *l*, on one end of whose axis is found the toothed wheel *m*, working into a small pinion *n*, moved by a crooked handle. When the ram is to be raised from the cylinder, it is only necessary to turn the handle of the pinion *n*; *o o*, are the cylinders for the material, and at the under side are the conical moulds *p*, which have a circular opening; *q* is a cast-iron cone, which is suspended to the centre of the mouth-piece by the rod *z*. The rod *z*, passes through a cross-piece *s*, the square edges of which are removed, and which is cast in one piece with the mould; *t t*, are cradles upon which the cylinders *o o*, are secured, and to which two polished cast-iron soles are attached, so as to be easily movable on the cast-iron rails *w*, which rest upon the cross-beam *B*; *X* is a toothed rod, which is screwed to the cross-pieces *y y y*, of the cradle or frame; *Z*, the lever by which the framing is moved so as to bring either of the cylinders under the ram of the press.

Fig. 208 is a ground plan of the cylinders, framing, and pump,

Fig. 208.

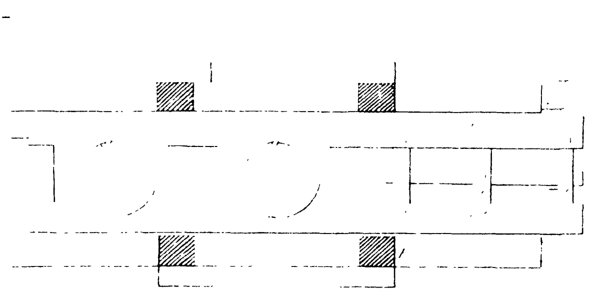
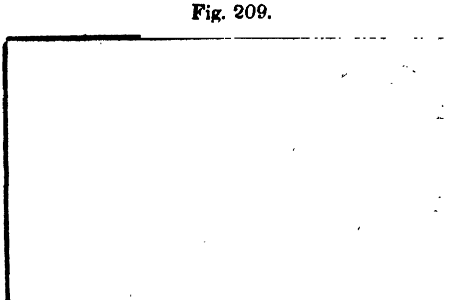


Fig. 209.



according to the line *A B*, in Fig. 207. Fig. 209 is a ground plan of the upper part of the framing, according to the line *C D*, Fig. 207.

When the materials have been properly prepared, and are in such a state of consistency as to be fit for the press, they are thrown on

the table E, in large masses. One workman fills the cylinder with these masses, while another beats them down, so as carefully to fill the cylinder without leaving any empty spaces. The top is covered with an accurately-fitting leather disc, and while the press is at work with this cylinder, the other, outside, is being filled. The pipes are removed at the bottom, by a workman, on a wooden tray.

The moulded pipes are dried in the gallery of a baking-kiln, being placed upright on a perforated support. Any other inclined position, or any obstruction to the draught of air passing through them, causes them to bend in drying; a want of uniformity then occurs, cracks are produced, and it is quite impossible to obtain tight and well-formed pipes. However dry the pipes may be when placed in the kiln, even when they contain precisely the proper qnantity of cement, many will always crack during firing, and always in a longitudinal direction. They would crack in a cross direction if any obstacle stood in the way of their contraction in length; an obstacle of this kind is only opposed to the contraction in diameter. The circumference of the pipe is shortened by the particles coming into closer proximity on the side where the contraction takes place, and separating or cracking on the opposite side. The furnaces are upright; the upper part for the first firing (biscuit), the lower for the glazed ware.

The application of the hydraulic press renders these pipes sufficiently strong to resist a pressure of from 35 to 40 atmospheres (above 1000 lbs. on the square inch), which, with pipes manufactured in the ordinary manner, would be perfectly impossible. Their dimensions are from 12 lines* in diameter with 5 lines thickness of substance, to 100 lines diameter and 10 lines thickness; their length may be 1 metre=4 feet Hessian. The running metre of a conducting pipe, including the connecting-pieces, weighed, of the first size, 3 lbs., of the last, 100 lbs.

5. STONES COMPOSED OF CLAY.

Historical.—It may be stated as literally true, that tiles and bricks are as old as history; the necessity for building in localities where stones could not be procured, and the observation that clay becomes hard by drying and burning, led at a very early period to their employment.

Artificial stones composed of clay have been in use as building materials since the period when the first civilized nations flourished between the rivers Tigris and Euphrates. In the ruins of Babylon and of Nineveh, very lately discovered by the French, immense masses of them are found, mostly composed of coarse material, crudely put together, and in an unfired state. They are nearly all covered with inscriptions in cuneiform letters, which it is remarkable were all illegible from without, being purposely built in. The extraordinary durability of these porous stones is astonishing, and it could hardly

* Line=$\frac{1}{12}$ of an inch, or 0.0888 English inches.

have been so great in a climate subject to more rain. Lenormant also found some unfired stones in the ruins of Sais, which must consequently have been 3000 years old. The practice of mixing straw or other vegetable matters with the clay, in order to ensure greater solidity, forms the subject of dispute between the Jews and the King of Egypt, in Exodus, chap. v. The palace of Crœsus, of Mausolus, of Attalus, and other extremely ancient buildings, were constructed of beautiful red, hard-burnt stones. It is said of Augustus that he transformed Rome from a brick into a marble city.

The object and the material.—The stones that are prepared from clay, are intended to replace natural stone whenever this is not to be had, or where the hewing and cutting are too expensive. The clay is moulded at once into such a form as is most convenient for the purposes for which it is intended to be used; thus, rectangular, many-cornered and wedge-shaped cakes are formed, (wall-bricks, paving-tiles, arch-stones,) or rounded and curved pieces, (as roof-tiles.) The thickness of these cakes never exceeds a few inches, in consequence of the contraction and difficulty of drying; and in the case of roof-tiles, &c., it is only sufficient to prevent brittleness and bending, and does not extend beyond a few lines.

To secure the proper solidity of these stones composed of clay, they are either simply dried clay slabs, or more or less burnt and baked, forming *bricks* and *tiles*. Economy in the production is a most essential point in the manufacture of these stones for building purposes, as they have always to compete with natural stone. For this reason, they are seldom ornamented with color, or diversified in form; the preparation of the clay and its purification is confined to very simple processes; all extra expense in digging or conveying the clay to a distance is for the same reasons impracticable. The clay employed in the manufacture of these articles is, therefore, such as occurs in all places near to the surface. The *loam* and *marl*, or the clay deposits of more recent formation, are consequently the materials of the brick and tile-makers. A better article is of course produced where potter's-clay or plastic clay can be obtained. These clay-stones being much thicker and more massive than any potter's-ware, are necessarily subject to much greater contraction or shrinking during firing, and will, under the same circumstances, be subject to crack and split, where thinner ware would remain sound. This defect is remedied as much as possible in the tileries, by mixing substances with the clay that are not liable to shrink in the fire. Sand, calcareous marl, coal and coke refuse, peat refuse, saw-dust, &c., are suitable materials, and sufficiently cheap for this purpose. Sometimes brick-earth contains sufficient sand or lime, at others a proper mean quality is obtained by mixing brick-earth that is too fat (that contracts too much) with a poorer variety (containing sand or lime). A few examples will render this practice more intelligible.

The fine muddy particles which are carried away by the rivers, are deposited, when the current has lost a great part of its velocity, long after the coarser particles have fallen or been left behind. This hap-

pens in the mouths of rivers where the extensive deposits of aluminous mud form the so-called deltas, and afford an excellent building material for the surrounding inhabitants.

Selection of the Clay.—From sources such as these, the brick and tile-makers in Holland, in the neighborhood of London, at the mouth of the Ganges and of the Nile, obtain their clay. In Holland, the mud from the bed of the Yssel is scooped up in sacks, and mixed with pit-clay to produce the material for making bricks.

At Paris, the plastic clay from Arceuil, Vauvres, &c., is used, mixed with refuse coal. Cheaper stones, but of inferior quality, are prepared from ⅔ds of a ferruginous sandy clay (which does not effervesce with acids, and consequently contains no lime or alumina) of a red color, and ⅓d of a calcareous gray sandy marl. The mass which composes the clay tiles so extensively used for floors, is an aluminous marl which occurs in the hills of Ecouen.

In London and the neighborhood, where, as in the greater part of England, bricks are the only material employed for building, the clay is obtained from the alluvial deposits which lie above the *London clay* in the London basin. When a cross section of these deposits is exposed, three several layers, differing in composition, may be distinguished. The lowest consists of clay containing gravel of all kinds, with fragments of chalk, &c., which is not generally used, and which passes gradually into the middle stratum (called malm), which likewise consists of clay, but mixed with finer fragments of chalk and sand instead of coarse gravel. In the upper layer, the clay preponderates, the gravel and sand are much less prominent, and so little lime remains, that the clay hardly effervesces with acids. The clay of the upper stratum is too fat, and is mostly worked up with coal cinders, (a mixture of ashes and small pieces of coke, which is collected from the fire-places of the town,) or with sand. The clay from the middle stratum only requires cinders, and no sand. The bricks of which the greater number of the London houses are constructed, are composed of the same earth that is dug from their foundations.

In America, the brick-earth is often advantageously mixed with refuse anthracite. Loam, mixed with sand, is the material chiefly employed in Germany.

Properties of good Bricks.—An opinion upon the value of any kind of earth for the production of bricks and tiles, can only be formed when the conditions which good bricks, &c., must fulfil, are borne in mind. These are:—

1. Bricks must be sufficiently hard and firm to support the height of wall which is piled upon them, without giving way, and they must also not be subject to break by carriage. The latter is particularly necessary with tiles.

2. In order to withstand pressure, the bricks must lie flat, and not hollow, upon one another; they must, consequently, have a straight and smooth surface, without hollows and cracks, which would diminish their power of resistance.

3. Great weight or density is also objectionable, as for building,

excessive weight is equivalent to want of solidity. In tiles that are employed for roofing, lightness is the most essential property. It is of no less importance that the bricks should possess the proper degree of adhesion for the mortar, a circumstance which is dependent on the density and porosity of the mass; the wet mortar must adhere to them in such a manner that it will form a durable cement when dry.

4. Bricks must likewise be capable of being dressed and formed with ease and certainty, *i. e.*, they must be hard and of uniform structure throughout, so as not to fall to pieces under the trowel, or split with difficulty, and in a direction contrary to that desired.

5. The influence of moisture and cold must not cause them to fall to powder or disintegrate.

6. Lastly, bricks that are intended to resist higher and often very high temperatures, as in flues, fire-places, chamber stoves and furnaces, must be constituted of such materials as will enable them to withstand sudden changes of temperature without fracture, and very great heats without fusion. In manufactories, smelting and other works, this property is of such paramount importance that the manufacture of bricks for this purpose has become a separate branch of the art, and will consequently be specially noticed below, under *fire-stones.*

The first glance will be sufficient to convince us that several of these properties must be altogether dependent upon the method of moulding and firing the bricks, whilst others, as the faults stated under three, five and six, must be attributed to an improper mixture, or to the impurities of the clay employed. Almost every variety of clay used in brick-making is either by nature a mass devoid of uniformity, or is an imperfect mixture of several kinds of clay. In both cases the want of uniformity will be perceptible in the finished brick, either as a difference of color, or by the lesser degree of solidity in parts, and the irregular mode of splitting when struck by the trowel.

Lastly, these varieties of clay nearly always contain foreign ingredients, which are very injurious if not removed.

Amongst these may be reckoned lime, which is not equally disseminated through the particles of clay, particles of iron pyrites, small stones and gravel, organic remains, &c., all of which will be affected differently from the burnt clay, and will consequently destroy its uniformity.

When clay, for instance, contains loam, particles of limestone, chalk, nodules or calcareous petrefactions, these will be burnt in the kiln to caustic lime, and will only melt with the clay where they come into actual contact with it. Whenever an opportunity occurs of water having access to the brick, and being able to penetrate to these nodules, the lime is slaked, expands, and destroys the brick.

Iron pyrites will be decomposed in the same manner, a portion or the whole of the sulphur will burn off, leaving a quantity of oxide of iron (or basic sulphate), which is insufficient to fill up the space previously occupied by the pyrites. All foreign substances in the clay, even those which are not altered in the fire, are objectionable, as they

produce cavities, which after burning are never entirely filled up. The cause of this is obvious. A small stone, for instance, expands in bulk in the fire, but the mass of clay contracts considerably and permanently. A cavity is thus produced by the stone in the clay, as the former contracts on cooling more than the clay, which cavity is no longer filled up by the stone when cold; the brick has therefore a tendency to break at that part in preference to any other.

Vegetable remains, roots, &c., are equally objectionable; they leave cavities when consumed, which the clay cannot prevent, in consequence of its porosity. Substances of this kind often occasion the splitting of the bricks by a sudden evolution of gas.

When larger rounded stones remain mixed with the clay, they often appear as projections after burning, if they happen to have been situated near the side of the brick. These stones do not alter their position in the fire, while the clay surrounding them contracts or sinks in.

The properties of the burnt bricks enumerated above, and their possible faults, are the guides for directing the selection of the clay. It is, however, nearly impossible to ascertain the applicability of any kind of clay without a direct trial. Although the mode of occurrence, the color, the plasticity, degree of purity, property of effervescing or not with acids, may all help in enabling the brick-maker to form a correct opinion as to the nature of the clay, yet it is always advisable to obtain complete certainty as to the suitableness of the clay for the purposes desired, by burning a few bricks by way of trial. The cases are naturally not frequent in which clay is obtained with all the requisite properties, and it requires a long series of experiments to ascertain what proportions of fat and poor clay, sand and other substances, should be mixed together in order to obtain a brick-earth of the proper quality. If the clay is too fat, the bricks will be denser than they should be, with too little porosity, and subject to bend and crack in the fire; if the clay is not fat enough, the bricks will be soft, and easily fall to pieces. In making these trials, the ultimate application of bricks must of course be considered. Clay may be very applicable for tiles, which is much too fat for bricks, the large amount of contraction being comparatively of little importance for the former application, and admitting of being more easily moulded, and yielding a denser, firmer, and more durable product than could be obtained from a poorer clay. Roofing-tiles can consequently be more easily manufactured from fat clay.

Fresh clay is not adapted for immediate use, partly on account of its impurities and want of uniformity, partly from the variable and insufficient quantity of water which it contains, but more particularly because it requires previous admixture with the substances mentioned above.

The ordinary processes followed in preparing clay consist in *exposing it to the air for some time, pitting and treading it.* The exposure of the clay to the weather and the air is practiced with the view of

softening it, and rendering it porous by time, which, if done immediately, would demand much labor and expense.

Frost is of essential service in rendering the clay porous; as are also rain and dew, which gradually permeate the clay and render it uniformly moist, and, in conjunction with the atmospheric air, disintegrate the foreign substances which are disseminated through it. A frozen lump of clay, as is well known, breaks up into a fine mud as soon as it thaws; the water, which penetrates the clay by capillary attraction, expands when converted into ice, and thus forces the particles of clay asunder, and these remain in this state, if the clay is prevented from becoming dry. The frost should, therefore, always be allowed to exert this action whenever it is practicable, and the clay be left to weather for several months.

Whether this process has been effected or not, the clay is always exposed in the pit (a boarded or plastered tank), and covered with a sufficient quantity of water to immerse and soften all the lumps, which operation is accelerated by frequent forcible agitation.

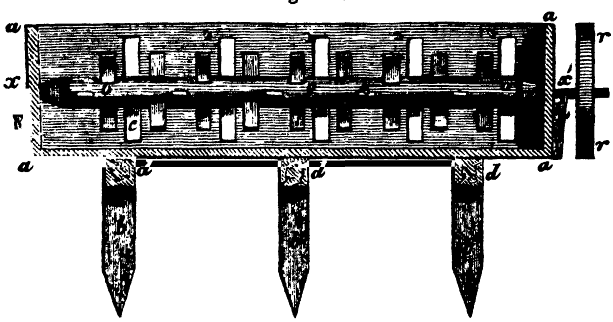
When the clay has taken up so much water, and has become so soft as to yield easily to pressure, the treading operation commences. A moderately thick layer is spread out upon a wooden floor, and trodden with the naked feet. A great advantage is gained by treading with the *naked feet*, as the workman is enabled to *feel* whether any roots or stones are mixed with the clay, in which case he removes them, and these would not be perceived if the operation were performed with boots or under stampers. More water is now poured on the clay, if necessary, and then again fresh clay, until the whole has become so stiff as to impede the action of the feet. If the brick-earth is composed of different kinds of clay, these should be mixed in the proper proportions in the pit. The sand, coal-ashes, peat refuse, and similar additions, are sprinkled over the clay on the treading-board and worked up with it. The treading must be kept up until the clay appears uniformly soft and moist through the whole mass. If this precaution were not observed, the less moist portions would contract more than the others, and distortions would occur. Clay prepared by treading, however, is never so perfectly uniform as the mass from which vessels are formed. The prepared clay is stored away in places (pits) where it can be prevented from becoming dry.

Wherever there is an extensive bed of clay and a regular and considerable demand for bricks, &c., where permanent brick and tile-works can be established, and more costly and perfect arrangements are practicable, as in the vicinity of populous cities, the preparation of the clay is carried on with much greater care, at more expense, and not unfrequently with the assistance of machinery. In England, for instance, the weathered clay is suspended in water, like slip, which is passed through a sieve, that separates the coarser particles, into a pit, where it is allowed to settle down. The excess of water is drawn off and evaporated, and the requisite addition of lime is made, if necessary. The cinders, however, are always trodden in; 1 to 1½

inches, according to the degree of fatness, being sifted on to a layer of clay about three feet thick.

Elutriating Machine.—In the manufactory of Henschel, in Cassel, where stones, pipes, and architectural ornaments are prepared from clay, a machine is used for softening and working the clay, which enables the manufacturer to dispense with the operation of treading. This simple machine, Fig. 210, consists of a quadrangular wooden

Fig. 210.



trough *a a a a*, which is supported on the beams *d d d*. These latter are attached to the piles, *b b b*, which securely fix the whole. Through the centre of the trough a wooden shaft, shod with iron at both ends *o o o*, passes, from which 19 spokes, *c c c*, project in such a manner as to form an angle of 45° with each other. The iron axle *x x*, of the shaft *o*, passes at both ends through the narrow sides of the trough, and is supported on the outside on the mortices *y′* and *y*. At *x′*, the drum *r r*, is fixed to the axle, which, by means of a belt, completes the connection of the machine with the motive power. When the trough has been properly charged with clay and water, it is covered on the top with a lid and the shaft is set in motion. The arms or spokes then separate, knead, and thoroughly mix the clay, until it is converted into a uniform slip. The fluid mass is then passed through a sieve into the mixing-pit, where the necessary additions are made, and the whole is transferred to the clay, or pug-mill, Fig. 191. The purification or cleansing of the clay is not altogether dependent upon the sieves, but, to a certain extent, upon the action of the machine itself. It will be seen in the drawing, that the spokes *c c* do not reach to the bottom or sides of the trough, but revolve at a distance of some inches from it, and some space is also left in the corners. A soft layer of clay settles down immediately in these parts, where it remains untouched by the spokes, and is, consequently, not converted into slip. All the coarser particles, stones, &c., press into this soft layer during the time the mill is at work, and are thus removed from the clay.

In Feilner's manufactory, at Berlin, the trough is constructed of cast-iron, the lid of wood, and the arms *c c* are three-pronged at the extremity.

Moulding by hand.—The moulding operation in the ordinary brick and tile manufactories is simpler than is the case with any other kind of clay-ware. The workman is supplied with a stock of clay by his side, a table or bench before him, and a helper. The moulds are four-sided frames of wood, or better, of brass, larger than the finished bricks, in proportion to the contraction which the latter undergo. The frames themselves only mould the four narrow sides of the brick, the one broad surface being produced by the table which supports the frame, and the other by a straight piece of wood, with which the workman scrapes away the excess of clay by drawing it straight along the upper edge of the frame. To prevent the clay from adhering to the mould, the wet mould is rolled in sand, which causes the moulded brick to separate, without bending or loss of time, from the mould. The operation is conducted as follows: the workman throws a lump of clay with great force into the sanded mould before him; the mass, which has become flattened by the shock, is forced into the corners by one or two rapid strokes with the hand, and that which projects beyond the mould is scraped away with the flat board. At this moment the helper returns with an empty frame, places it on the spot previously occupied by the filled one, and carries the latter to the drying-place, where it is deposited upon the exact spot that is to be occupied by the brick during the first part of the drying. As soon as the frame is withdrawn, which must be done with care, to avoid injury to the corners and edges of the brick, it is dipped by the helper into water, then into sand, and speedily carried back to the moulding-bench, to be exchanged for the first, which by this time has been re-filled.

The number of bricks which a workman can mould in a certain time is always very considerable, but depends very much upon the ability and strength of the moulder. The statements are, in consequence, at variance upon this point, and the number which a brick-maker is said to be able to make in a working day of 12 hours varies from 2,500 to 10,000, or from three to fourteen in the minute. According to Simms, the mean produce in a week, of a moulder, treader, carrier, and two boys at the brick-works of the London and Dover railway, amounted to 16,000 bricks. That the quality of the clay is of the utmost importance, is proved by a remark of the same gentleman, when he states that thirty sand-stock-bricks require only the same time in making as 16 slop-bricks, which, calculated in wages, gives a proportion of 4 : 7.

Moulding by machinery.—The moulding of bricks is consequently a very cheap process. In England, where labor is dearest, the cost of moulding is about ⅓ of a penny for 22 bricks; in Germany, 67 bricks may be moulded and partially dried for the same money, calculating the daily wages of the moulder as 1*s.* 3*d.*, of the helper 10*d.* and the produce of their joint labor at 5000 bricks. The cheapness and simplicity of the hand-process render it difficult to devise machinery that shall supersede it; the produce of the moulder is nearly equal to that of a machine, and the prime cost and expense

of keeping machinery in order are only likely to be remunerated where circumstances are very favorable, and a great outlay of capital is desirable. These combined circumstances seldom occur together. The interest of capital, the necessity of keeping a machine constantly at work, and the cost of the motive power which such machines require, demand a constant and very extensive market for the produce, if the undertaking is to succeed. So large a consumption is seldom possible, as the price of the bricks will not admit of carriage to a distance; it is, therefore, not surprising that machinery is so seldom employed by brick-makers.* It will, however, be proper here to notice the principles upon which the machines are constructed. They may be divided into the following kinds:

I. *Machines with actual moulds, similar to hand-moulds.*—A single mould is used, which is filled, smoothed and moved by machinery.

The mould is first brought under the clay-machine to be filled, whence it passes under that part of the machine which presses the clay into the mould, and lastly, is deposited exactly above a piston which, from below, raises the brick out of the mould.

The machines invented by Knisley in 1813; Delamorinière in 1825; Thierrion, of Amiens, in 1829; Carville, of Issy, near Paris, in 1840, and lastly and most recently, by Choice and Gibson, and Mac-Nab, are constructed upon this principle; in several, however, the backward and forward action is converted into a continuous motion.

II. *Machines in which the moulding is performed by several moulds, arranged upon a revolving plate or upon the curved surface of a cylinder.*—In the first case, the motion is either backwards and forwards, or rotary, round a perpendicular axis; in the second case, it is rotary, round a horizontal axis. In Forsyth's machine, for instance, a steam piston presses the clay contained in a cylinder on to a movable mould-frame, which forms the bottom of the cylinder. This mould frame is divided into a number of quadrangular compartments (which are the brick-moulds) and is moved backwards and forwards, so that the half of the moulds are alternately brought under the piston and filled, while the other half are discharged on a drying-board by a part of the apparatus which pushes the bricks out of the moulds.

Amongst this class of machines with movable mould-plates, are those of Doolitle, 1819, used in the neighborhood of Washington; of Levasseur-Précourt (patented in 1826); those of Champion, Fabres and Janies-Dubry, of Besançon (patented in 1830), as well as that of the Marquis of Tweeddale for walling bricks.

Among the cylinder-machines are those of the Baroness Gavedal-Geanny (patented in 1826); of Naudot and Co. (patented 1828); of Cartereau (patented 1829), and the more recent machines of Leahy and of Nash.

* The rapidity with which cities are springing up in the United States, the expensiveness of manual labor, the cheapness of fuel, to drive steam engines, and the steady demand for bricks, cause much use to be made of brick machines in this country.—*Am. Ed.*

III. *Machines which cut out the bricks from a cake of clay, in the manner in which ornamental pastry is made from dough.*—In this case the machine must prepare a cake of clay of the thickness that the brick is intended to be. When a sufficient pressure is exerted, architectural ornaments in bas-relief may be moulded, as is the case with Verebent's machine, of Toulouse (patented in 1831). The machines invented by Cundy in 1827, by Bosq, brothers, Girault and Taxil, brothers (patented in 1829), belong to this class.

IV. *Machines which produce a continuous strip or band of clay, and subsequently cut it into separate bricks.*—A strip of this kind forms a parallelopipedon of indefinite length, the thickness of which corresponds to the thickness of the bricks, and its width to their breadth. When, therefore, a piece of this strip is cut off of the length of a brick, it will correspond precisely with a brick in dimensions. The production of the band of clay in this machine is similar to that practiced in manufacturing maccaroni, or to the process of wire drawing, *i. e.*, the clay is delivered from the clay-mill into a cylinder, the piston of which forcibly presses the contents through an aperture of the dimensions stated above; the strip thus produced, passes through rollers which improve its shape, and is then received upon a horizontal surface, where it is cut into lengths by wires moving in a vertical direction up and down. The cross section of this strip may of course be equal to the thickness of 2 or 4 bricks. The cutting machinery is then more complicated, and is made to cut 2 or 4 bricks at once. Machines of this description have been invented by Hostemberg (1807, used in St. Petersburg); by Georges of Lyons (patented 1828); and by the Marquis of Tweeddale for roofing-tiles, and by Terasson-Fougères, who obtained a medal in the same year from the Société d'Encouragement. In the last named machine, 10, 20, 30, up to 40 bricks, can be cut at once.

This machine, Figs. 211 and 212, consists of a large rectangular wooden frame-work, strongly bound together by cross-pieces, and strengthened lengthways by three iron bolts. The whole machine is supported on six uprights, arranged two and two, connected together by cross-pieces, which run upon rollers, so as to render the machine easily movable.

At the posterior part of the machine and a little below the ends which form the termination of the longer sides, there are two hollow drums, *V*, *W*, which carry an endless belt, upon which are fixed the pieces of wood, *E*, *E*, forming a species of chaplet, and whose elevation on either side is regulated by the transverse guides which are bound together, two and two; these guides are also intended to support the moulding-board, and the lateral pieces of wood, *E*, *E*, to regulate the level of the clay.

The posterior drum, *V*, can be drawn back by means of screws, placed on each side of the framing, which also work the little rollers that support the axis of the drum, thus preserving the endless belt in a proper state of tension. The anterior drum, *W*, carries a notch-wheel, *d*, *D* on an extension of its axle, which communicates by means

of a pinion with the handle *G*, in such a manner, that when the handle is turned, the anterior drum moves and carries with it the endless belt and second drum. But as the large cylinder *C*, called the "compressor," can be fixed at any convenient height by means of the screws which support the little rollers, it is made to revolve as soon as the belt approaches filled with clay ready for moulding. A piece

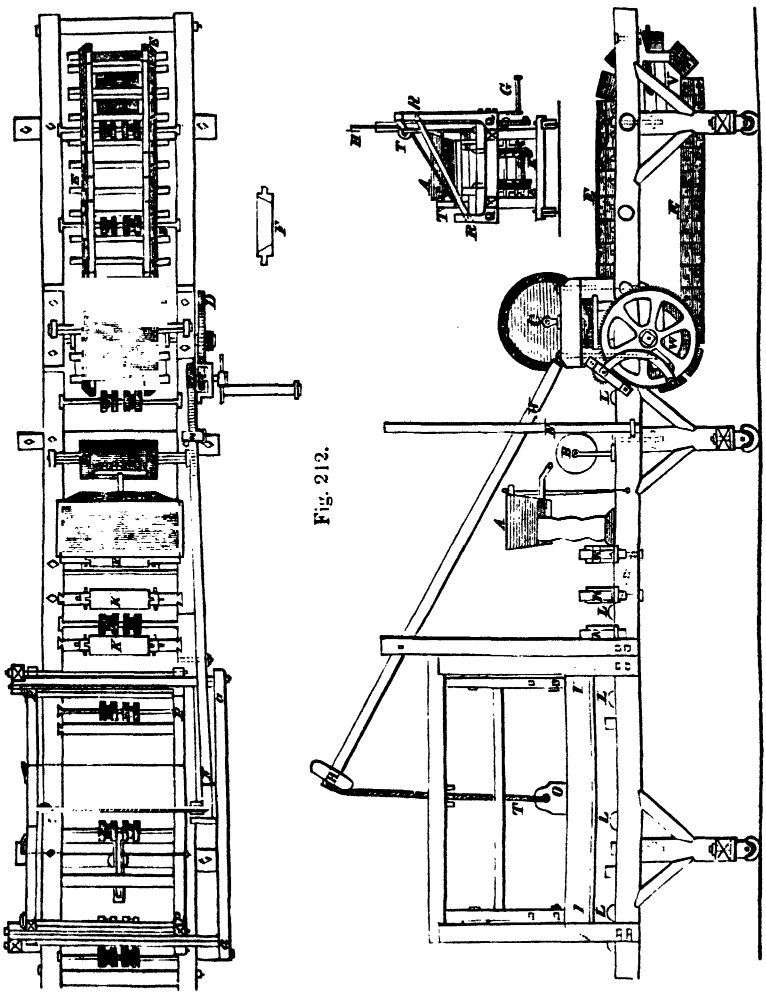


Fig. 211.

Fig. 212.

of wire is placed the lengthway of the machine, a little in advance of the compressor, and on a level with the upper surface of the moulds, so as to remove the excess of clay and prevent it adhering too strongly to the compressor.

The wooden planks which are forced one after another upon the transverse guides of the endless belt, and whose length must not exceed the extreme limits of the frames *P*, *P*, gradually advance, while

the rectangular funnel is kept full of the prepared clay by manual labor, or from wagons placed directly above.

The clay and the planks, after having passed under the compressor, spread out in sliding over the rollers, *L*, under another cylinder, *B*, which is covered with a woolen cloth, preserved always in a moist state by a small current of water from the cistern, *A*, in the form of a gentle shower from numerous wires. The movement of the cylinder *B* is regulated carefully by means of a screw, which lowers it in such a manner as again gently to compress the brick. This compression is affected by a moist body, and gives a glaze to the upper surface of the brick, while the excess of clay on either side is removed by wires, which are attached at one end to the frame of the machine, and at the other to the sides of the cistern, *A*, and which can be easily stretched or arranged by screws.

The bricks are perfected by passing through three moulds, *K*, *K*, *K*, the size of each of which is smaller than the preceding. They are lined with thin sheet-iron, and the transverse section is shown in *F*.

The planks, as they arrive, force the others forward, until one of them becomes exactly parallel with the large frame *P*, *P*, which can be easily made to slide over the inclined plane *R*, *R*, by means of small rollers. This plane is firmly secured to the base of the machine by the arrangement *Q*, *Q*.

A notch attached under each plank and a clock-like arrangement, sets in motion the hammer of a small clock when the prism of clay has arrived at the proper point, and thus announces that it is time to divide it. The workman employed at the handle, immediately stops, and raising the extremity of the lever, *H*, which moves in the groove, *N*, loosens the cord *T*, *T*, which suspends the frame *P*, *P*. This latter descends the inclined planes *R*, *R*, by its own weight and that of the lead, *O*, which is attached to its lower end. During the descent, it cuts the prism of clay according to the required dimensions, by means of the transverse wires placed horizontally at its inferior part, and which, arriving obliquely on the surface of the prism, divides the clay very neatly, without injuring it. When this operation is finished, the cutting-frame is returned to its original position, and the working of the machine is recommenced. The planks which carry the finished bricks, are removed to the air to dry by rolling down long ladders, slightly inclined, the bars of which are cylinders, easily movable round their axis. When the machine is making larger bricks, it is preferable to allow the workmen to carry the planks to the drying-rooms. The planks must be sanded before they are placed on the endless belt, and this is best done by watering the planks at a pump, and coating them with sand by means of a fine sieve.

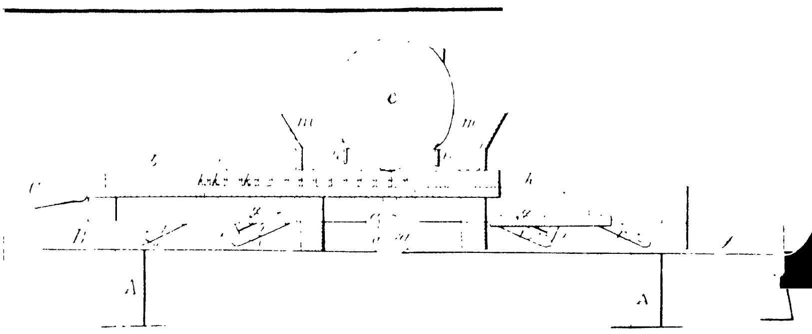
This machine manufactures daily about 25,000 bricks of the ordinary dimensions, and costs from £30 to £38 (= 145 to 184 dollars).

[On the 16th of May 1846, Mr. J. Culbertson, of Cincinnati, received a patent of the United States for an improvement in brick-presses, in which the pressure is given by a heavy roller, the same as in that of

Terasson-Fougères. But in all its other arrangements it is entirely different, and far less complicated in its construction.

Fig. 213 exhibits a longitudinal vertical section of this machine.

Fig. 213.



m m is a hopper to receive the clay, its sides flare above, but are vertical below to allow the clay to descend freely to the moulds which pass under it. These moulds are seen, at *i i i*, in the sliding-frame *b*, put into alternating motion by the connecting-rod *C*.

c is a heavy pressure roller, the weight of which is increased by the weighted pressure-levers *f f*, connected with the axis of *c* by straps. The purpose of this roller is to press the clay into the moulds *i*, *i*, *i*, &c. In each of these moulds is a false bottom *k*, *k*, *k*, and from each false bottom there extends downwards a stem *l*, *l*, *l*, and which serves to elevate the false bottom, and remove the brick when completed.

h h are the iron rails or ways on which the carriage *b*, slides.

n n are gauge-plates, or scrapers, intended to remove surplus clay from the surface before the filled moulds pass under the roller *c*.

o o are knives to smooth and finish the brick after it has passed under the pressure roller.

These knives are inclined across the surface of the brick, and are fixed to the sides of the clay box by an arbor at the back of each knife which allows its edge to rise when obstructed by stones or other hard material.

a is a bearing roller, on which the frame *b* rests, and over which it traverses. It is reduced in diameter as at *a' a'*, to allow the stems *l*, *l*, to pass over it.

When half of the moulds have passed out from under the roller *c*, their stems come over the plate *g*, which is supported on parallel moving-bars *r*, *r*, turning on gudgeons *s*, *s*.

An arm *t*, is at the same time struck by a tappet on the moving-frame, and *g* is then brought into contact with all the stems *l*, *l*, raising *k*, *k*, and carrying the bottom of the brick quite above the top of the sliding-frame *b*. A laterally moving frame is then made to slide across the moulds and remove all the bricks to a side bench. On the return of the sliding-frame, *g* is depressed by the tappet and the movable

bottoms again return to their places. When the reciprocating motion of *C* has carried the opposite end of *b* beyond the hopper *m*, the other parallel frame raises its plate *g′*, and the second half of the bricks of the movable bottoms are raised and made to deliver their bricks at the opposite end of the machine from that which received the first half.

The laterally moving bar which pushes the bricks off from the moulds when finished carries with it a long sand-box with a sieve-bottom, which, in passing across the moulds, going and returning, scatters sand into them, to ensure the easy separation of the following charges of bricks.

The whole of the machinery rests upon the strong frame *B*, supported by the uprights *A*, *A*. The frame *B*, and connecting-rod *C*, are seen to be broken off at the left, in which direction, on a prolongation of the frame, the moving machinery is placed.

It will be observed that as the plate *g* rises on the parallel jointed frame *r*, *r*, it also advances in the same direction with the sliding mould-frame *b*, so that the stems *l l* are continually lifted vertically, and not forced obliquely against the bottom through which they pass. This constitutes the first novel feature and ground of claim.

The jointing of the knives *o o* is regarded by the inventor as an important feature of his machine, and is the ground of his second claim.

The gauges *n*, *n*, in combination with the roller *c*, make the basis of his third claim to novelty, and the employment of the movable bar above mentioned for removing the bricks as above described, and in combination with the sand-hopper to dust the moulds, the fourth.

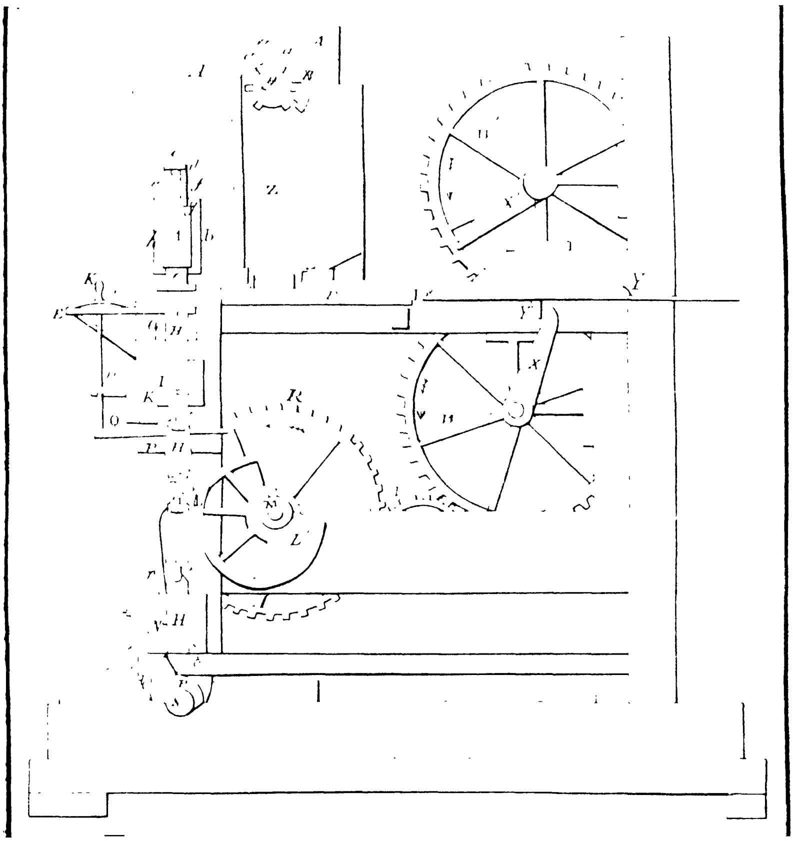
An improvement has been made in Culbertson's press, by Mr. Gregg, which consists in making the moulds deeper than the thickness intended for the finished bricks, and, after the pressure has been given, causing the stems *l*, *l*, &c., to be lifted a sufficient height to enable the knives *o o*, to cut off a definite thickness from the pressed brick, leaving the required thickness of brick below; having passed the knife, and been thus rendered entirely smooth on their upper faces, the bricks are carried as above described over the plate *g*, then elevated and pushed away to the receiving bench, as already described.]

[On the 4th of December, 1847, a patent of the United States was granted to Mr. Nathan Sawyer, of Baltimore, for a brick-press for forming bricks from dry clay.

This machine embraces a *pulverizer*, a hopper, a filler, a press, on the toggle-joint principle, and an elevator by which the whole press, while yet retaining the bricks under pressure, is elevated bodily, carrying the bricks upward to a height at which they may be delivered from the moulds. This press is represented at Fig. 214.

The *pulverizer* is seen at *Y′*, which is a roller furnished with numerous rows of teeth *a a*, working, as they revolve between, and projecting above, curved grate-bars *a′* (which form the bottom of a hopper for receiving the rough clay), and also between projecting teeth on a concave arc *B′*, underneath the grating of bars *a′*. The concavity of *B′* is concentric with the convexity of the pulverizing roller *Y′*.

Fig. 214.



Z is the trunk or receptacle for the pulverized clay, from which it descends into a cavity in the filler *F*, sufficiently large to contain the quantity required for a brick. Having received its charge, the filler is pushed forward by the movement of the arm *X*, acted on by the toothed wheel *W*, so far as to bring the charge of clay between the two platens c' c'', of the press. At that moment the lower platen on the upright *H*, is depressed into the mould, by the bending of the toggle-joint pieces H' H', to the right, which is effected by the action of the spring *r*. By the time, therefore, that the charge of clay in *F* arrives above *H*, the cavity of the mould in which c'' moves up and down, will be ready to receive it, and, having deposited its charge, the revolution of the wheel W' brings the arm X' in contact with the tappet Y'', which at once carries the filler backward beyond the reach of the press, as seen in the figure. At this moment, by the revolution of the cam *P*, on its axis *S*, the whole press is allowed to descend vertically along two guide-rods far enough to bring the upper platen c', within the upper opening of the cavity *G*, of the mould. At this

time the limb L' of the wiper on the axis of the wheel R, comes in contact with the flexed toggle-joint $H' H'$, moving about its bolts t t, and commences the pressure by forcing upwards the platen c''. Having given the necessary pressure, and consolidated the pulverulent clay into a solid hard brick, the press is again elevated by the cam P, raising c' high enough to allow the brick to be withdrawn when raised out of the mould by the rising of the platen c''. The manner in which the brick is removed is by the advancement of the filler F, and its striking the pressed brick so as to force it from the platform of the press to a bench from which it may be carried by the workman, and at once deposited in the kiln. Q is a wedge resting on a projection p, of the frame in which the press is mounted. It serves to limit the range of motion of the lower platen downward, and thus to regulate the quantity of clay which the filler can leave in the moulds. This wedge is pushed forward, or drawn back, by the lever K, having its fulcrum at n, and is held by a spring creating friction at i.

The two cross-heads N and B, both rise by the motions of the cam P. The upper cross-head is traversed vertically by the piston C, that rises up against a coiled spring f, which is compressed upward when the toggle-joint is straightened so as to make a solid bearing against the top bar d, but when the pressure is relaxed, and c' and c'' begin to separate so as to release the pressed brick, the elasticity of the spring prevents the *sudden* removal of the upper platen from the face of the brick, which would, by such sudden separation, be torn and disfigured. By the arrangement of the two cams P and L, the whole press rises, while the pressure continues on the brick, and remains at its maximum intensity until it is lifted nearly clear of the mould.

The nut g serves to regulate the extent of action of the spring f.

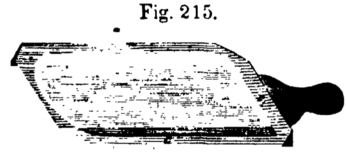
The principal novelties claimed for Mr. Sawyer's press are, the peculiar construction and arrangement of the pulverizer, the continuation of the pressure on the brick while it is being removed from the mould, and the gradual removal of that pressure, in consequence of employing a spring to keep the upper piston or platen for some time to its bearing, after the toggle-joint begins to be flexed so as to relax the pressure.]

Drying.—It has already been stated, that the moulded bricks are laid flat upon the drying-ground by the helper. As they become stiff by drying, and the danger of bending diminishes, they are first set on edge, and, lastly, piled 3, 4, or 5, one upon the other in the same position, leaving, however, spaces between them that the air may thoroughly penetrate through the dwarf wall. During the night, or when rain is apprehended, and whenever the weather and drying cannot be constantly watched, the walls and sides are covered and protected with boards and straw. It is here and there the custom to improve the form of the half dry bricks, by striking them with a flat board, which very much improves their quality, and is to be recommended whenever the price will admit of the practice. The process of drying is well illustrated by the following example: A

brick (9.9 inches long, 5.1 inches wide, and 2.6 inches thick) weighed, when newly moulded, 94 ounces; previous to burning (thoroughly air-dried, therefore,) it weighed only 72 ounces, and after burning 68 ounces. During drying 22 ounces of water have consequently disappeared, 9 ounces in the first 24 hours, and 13 ounces during the rest of the time, *i. e.* in 5 or 6 weeks. The dry stone still contained 4 ounces of moisture, which were expelled in the kiln. In permanent brick-works the bricks are dried under sheds. These consist of scaffoldings of laths, open on all sides, but covered with a roof: after moulding, the frames are discharged upon boards, which are arranged in rows with the bricks, upon the scaffolding. Roofing-tiles are always dried in this manner, as these cannot be piled one upon the other; they are moulded, however, in a somewhat different manner.

Moulding Roofing Tiles.—The form of the tiles is somewhat different from bricks; they require to have a projection, or *noze*, in order that they may be hung upon the roofing-laths. The moulds employed in Germany, Fig. 215, consist of a flat board with a handle, round which a rim, *c c*, of the thickness of the tile, is nailed. The rim is so shaped as to produce the form of the tile, while the nose is moulded by the cavity *o*. The workman first covers the mould with dust (from the turnpike road, or finely-ground dry clay), he then throws a ball of clay upon it, presses this firmly into the corners and into the cavity, *c*, cuts away the excess of clay with a wire drawn along the rim, and puts it on one side, to be smoothed on the cut surface with a flat piece of wood. When the tile is thus moulded, the mould is held by the handle, and the tile turned out upon the drying board. Curved tiles for ridges, &c., which are in the form of an arch, are first moulded in a flat mould, and afterwards bent upon a round block of wood. The red color is produced by dipping the air-dried tiles into slips composed of ferruginous loam, or ochry clay.

Fig. 215.



It is obvious that tiles may be formed in the same manner as bricks with the machines described above. The nose, however, gives rise to some difficulty, and must generally be applied in a separate operation.

A great deal of ingenuity has been shown within the last few years in inventing machines for the manufacture of agricultural tiles, but it would exceed our limits to enter into the detail of these machines. They are mostly constructed upon the principle of forcing the clay from a cylinder through a die-plate fixed to the extremity, which delivers the tiles in the various forms required for draining, &c.

Firing or Burning.—Brick and tiles are burnt, as may easily be conceived, in very different ways. The nature of the fuel which the brick-maker has at his disposal, cost and custom must all be taken into consideration; but these are not the only circumstances that in-

fluence the process; it is dependent quite as much upon whether the work is permanently stationary, or whether it is carried on periodically at different places, wherever clay is to be had, for buildings on railways, &c. None of these circumstances settle definitely the plan to be adopted, but they influence the general arrangement; the price of fuel and labor being also brought into the calculation. The different arrangements for burning bricks and tiles may be advantageously considered under two points of view:

1st. A special kiln is either built which is charged each time with the goods to be burnt, as in the potteries, and these furnaces may be *open*, *close*, *horizontal*, or *vertical*.

2d. Or the bricks are piled one upon the other, and so covered as to form a kind of temporary furnace or *clamp*.

Clamps are well adapted for burning a large number of bricks at once; but they are not applicable for finer kinds, where a sharp outline is required, as, for instance, for roofing-tiles; they are best calculated for coal as fuel; peat and wood cannot be used so advantageously.

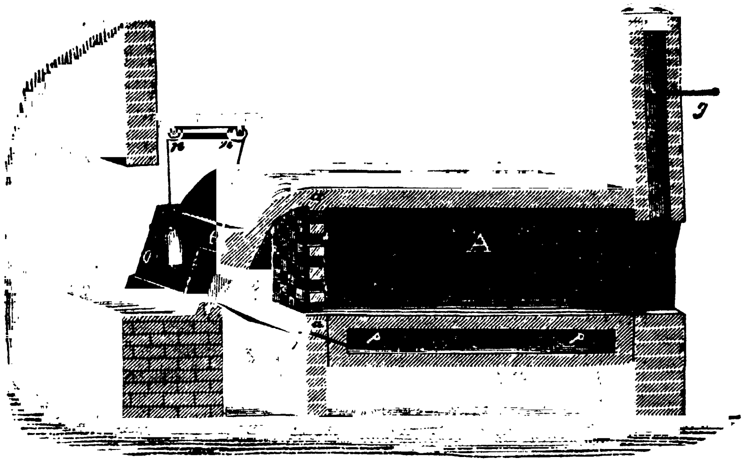
Kilns.—Kilns, on the contrary, can be used for all kinds of bricks and tiles; they burn a lesser number at once, and are connected with expense in building, from which the other plan is entirely free.

Both plans are subject to one objection, to which some few vertical kilns form the sole exception, and that is, an imperfect regulation of the temperature. This evil is only of importance in consequence of the easy fusibility of the clay from which the common bricks are made. The large number of bricks that must be fired at once, obliges the fireman to overheat those which lie nearest the fire, in order to burn the more distant ones thoroughly; the former then melt and bend, cake together into clinkers, and, in short, are spoiled.

Instead of further description, a few examples will illustrate the principles upon which the manipulations and arrangements connected with the firing depend.

Horizontal close Kilns.—The horizontal kiln, Fig. 216, is that recommended by Henschel, and is employed everywhere in the neighborhood of Cassel. Although intended for bricks, it may be used very advantageously as an ordinary potter's kiln (compare page 305). *A* is the firing-kiln, *B* the fuel-grate, *C* the ash-pit, and *D* the chimney. The fire proceeds from the narrow end in a horizontal direction through the whole length of the kiln to the chimney. Below the flue is the door *b*, which is bricked up during every operation. The perforated wall, *a*, *a*, separates the fire-hearth from the burning-chamber, and diffuses the flame uniformly over the whole front part of the chamber. The position of the fire-grate in these kilns is to be highly recommended. The grate, *r*, is inclined towards the kiln, to facilitate the addition of fuel, while the curve in the roof conducts the flame, without interruption, into the burning-chamber. The fire-door, *e*, can easily be drawn up in the inclined front wall by means of the weight, *o*, and the chain passing over the pulleys, *n*, *n*. The flue *p*, and a few others of smaller size, in the side walls of the kiln, tend to

Fig. 216.



keep the brick-work dry, which is an important point in getting up the heat. The tile-kilns in the Low Countries, which are similarly, though more crudely, constructed, are very faulty in this respect. These kilns are often found sunk in the earth to the height of the grate (that the charge may be more readily introduced), without any precautions having been taken for conducting away the moisture. The door is frequently found incapable of being shut close, and the brick-work loose and unsound, under which circumstances it is quite impossible to regulate the heat with any degree of accuracy. In Henschel's kiln, an iron damper, *g*, is attached to the flue, that the regulation may be more under command. Through an aperture, that can be closed, two or three inches above this plate, the latter may be covered with sand, so that the draught may be completely stopped during the time the kiln is cooling. The furnace should be bound round with wrought iron, to render it more durable.

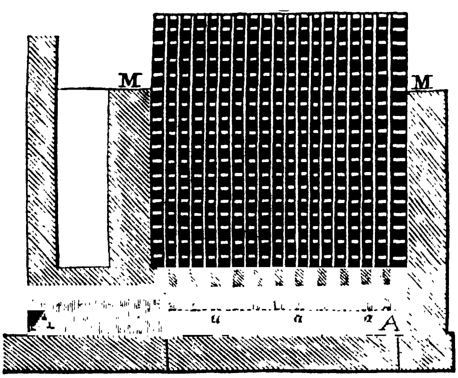
It is obvious that the heat in this, as in all similar kilns, must be very much greater in the neighborhood of the wall, *a*, *a*, than near the flue. To prevent the vitrification of the bricks, a certain quantity of lime is generally thrown into the front part of the kiln, which is not injured by the intensity of the heat.

In a furnace like that in the drawing, the firing-chamber of which is 3½ feet high, and 10 feet long, one of the smallest kilns therefore, the consumption of brown coal from Cassel (for the heating value of which *see* Vol. i. p. 83) was about 24 cwts. for burning a full charge of 6,000 bricks, with the necessary amount of lime, and this was effected in from 48 to 52 hours. Most of the German kilns contain twice that number, and more; in these a smaller proportionate quantity of fuel is required. In cases where wood is used in place of coal, the chamber should be proportionally longer, as wood produces a much longer flame.

In Würtemberg, the common brick-kilns were very much improved several years ago by Weberling, who introduced good close kilns. Formerly, 10,000 bricks were burnt in 3 or 4 days with a consumption of 7 klafter* of birch, or 9 klafter of pine wood, or from 24,000 to 30,000 peat bricks. At the present time, the consumption in one of Werbeling's kilns, charged to the same amount, is 2¼ to 2½ klafter of birch, or from 3 to 3½ klafter of pine wood, or 10,000 bricks† of air-dried peat, and the whole is burnt in 2½ to 3 days.

In a close kiln, at Hellmann's brick manufactory near Hanover, which was, however, of much larger dimensions, the following results were observed. The firing-chamber is 8 feet from side to side; to the top of the arch it is 12 feet 8 inches high, and its length is 20 feet 4 inches, so that it will contain 24,000 bricks. The amount of coal consumed in firing this charge varies with their quality, but in the mean, is about 260 cwts. This kiln is heated from both the narrow ends at once, from 4 grates. The grates join in the centre, *i. e.* the fire-places extend from one narrow end of the furnace to the other; there are, therefore, 4 traversing fire-grates, side by side, terminating at both ends. This arrangement secures a greater and more uniform distribution of the heat, and is in that respect similar to the *open* brick-kilns, Fig. 217, which, as represented in the figure, are intended for wood fuel. The drawing represents a section through the narrow side, in the direction of the firings, of which there are three, side by side; *A*, *A*, is the middle one. This fire-pit is without any grate, and arched over with a series of girders, *a*, *a*, *a*, which form a perforated covering, and cause a division of the flame before it passes into the burning-chamber. The latter consists of a long rectangular space, *M*, *M*, open at the top, and uncovered; the drawing represents the narrow side, the other being about ⅓ longer. The bricks are arranged on the arches, *a*, *a*, on their edges, in such a manner that the bricks in the different layers cross each other, and are so far separated from each other that the flame finds a free passage between them. In these open kilns there is always danger of losing too much heat, but this defect is, in some measure, remedied by piling the bricks to any height, required by the nature of the fuel employed. The loss of heat is also compensated in practice by the much greater ease, and consequently lesser cost, with which the bricks are stored

Fig. 217.



* 1 klafter = 144 C.F.

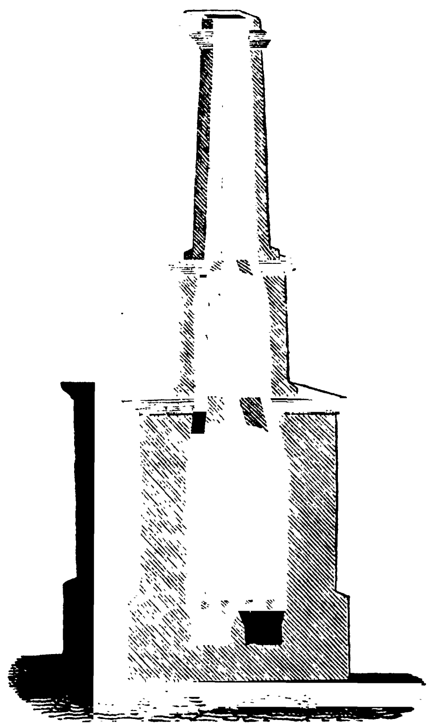
† The brick reckoned at 10 oz. this would be about 62 cwts. of 100 lbs.

and packed in the open kilns. In the great open kiln at the iron-works of Schussenried, in Würtemberg, (the space for burning is 28 feet long, 18 feet wide, and 14.5 feet high,) the consumption has been found, during the 3 to 4 days required for burning a charge of from 45,000 to 46,000 bricks, to amount to 60,000 peat bricks, which weigh about 900 to 1,000 cwt., and are equivalent to from 24 to 30 klafters of pine wood.

To retain the heat better, the top is covered during firing with a layer of brick-dust, and this is again covered with moist sand while the bricks are left to cool.

The open kilns of the Dutch are still larger; Heren describes one 51 feet wide, 110 feet long, and 25 feet high, containing 56 layers of bricks, one above the other. It contains more than 3 millions of bricks, which are burnt in 36 days by the flame from 10 fires, situated on both sides, during which time about 1 million peat bricks are consumed. The firings are merely open ditches or channels, not arched (a very common case), the top of the channel being composed of the first layer of bricks to be burnt. The lowest layer is spread asunder; in the uppermost, the bricks are arranged close together, but in such a manner that parallel spaces are left for the circulation of the flame. The fire in these kilns is below the burning-space and not by the side of it, so that the open kilns resemble in this respect the vertical *close* kilns, of which Fig. 218, or that constructed by Bihl, in Waiblingen, is a good example. It is heated by two fires upon the same principle as the last was heated by three; between the fires and the chimney, *A*, (which is altogether wanting in the open kilns), there are two working-chambers, a lower chamber, *C*, for burning, and an upper chamber, *B*, for drying the goods. Both are quadrangular in section. The working-chambers and chimney are separated from each other by perforated arches, the lower arch, *a*, above the fire being perforated with 25, the one above it (between the burning and drying-chamber) and the uppermost (between the drying-chamber and the chimney) having 13 apertures for the passage of the flames. Both the burning and dry-

Fig. 218.



ing-chambers and the chimney are furnished separately with doors for introducing the charge and cleaning. The fuel is placed not only below the chief chamber, *C*, but also in front of it, in a prolongation of the fire-channels, *a*, *a*, in which the grates are set. Bihl's kiln is less applicable to common purposes than for finer wares, as clay-slabs, pipes, &c. (page 307). In a similar kiln (as at Friedberg, in Hesse), for burning 600 roofing-tiles, 1,500 bricks (and 30 measures of lime), 130 cwts. of an earthy dusty-brown coal from Bauernheim are consumed, which is there made up into bricks.

Field-burning or burning in clamps.—The process of burning in clamps was introduced from the necessity of burning bricks in localities so far removed from any brick-works as to render the carriage upon the bricks too expensive, and where circumstances were such as would not admit of a permanent brick establishment. The great simplicity of the process has given it the preference in several countries, as in Belgium and England. The process consists in arranging and piling the bricks upon an even foundation in such a manner that all the essential fire-flues, channels and interstices for depositing the fuel and evolving from it the proper quantity of heat are produced by the bricks themselves. The bricks are stacked in the same manner as in the kilns, so as to form temporary kilns, just as the meiler or mounds are erected in burning charcoal.

These clamps, which are always erected in the open air, must be protected from a too free access of air, which would inevitably cause the combustion to proceed too rapidly in one direction, and give rise to a powerful and very injurious red heat if a slight wind should prevail, entirely putting an end to all control over the fire. The clamps, which often comprise as many as 500,000 bricks and more, are covered outwardly with a coating of loam, and protected against the wind by movable hurdles of straw. A clamp, in which there are 28 layers, one above the other, requires from 8 to 10 days in erecting.

When peat, brown coal, or wood are used as fuel, the process of burning is precisely similar to that in the kilns; *i. e.* the fuel is placed in channels situated in the lowest parts of the clamp, while the flame permeates the interstices and make its escape at the top. If coal is used, which is a dense fuel, and easily reduced to a small size, fire-places are also arranged at the bottom of the clamp, but small coal is strewn in layers amongst the bricks, so that the combustion, as well as the flame, spreads itself all over the clamp. It might be imagined, that in consequence of the expansion which must at first obtain and the subsequent contraction of the clamp, from the consumption of the coal on which the bricks rest, &c., that there must be great risk of the whole erection falling in.

When the clamp has been carefully built up, however, this is seldom the case, although a very considerable diminution of volume occurs. The erection of the clamps and the process of burning, demands, of course, a much longer time than would be necessary in the kiln, lasting, according to the size of the clamp, from 20, 30 to 50 days. The loss by fracture, clinkers, &c., is calculated in this country at 10 per cent.

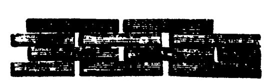
Considering the easy fusibility of ordinary brick-earth, and the slight difference which exists between the temperature at which the bricks must be baked, and their fusing point, and which is less than with any other kind of clay-ware, and when, lastly, the great disparity of temperature to which they are exposed in all the different methods of burning is borne in mind, it will not appear remarkable, that in every burning, the same bricks will be very differently affected by the heat according to the position which they occupied with reference to the fire. Those which were situated close to the fire and had to bear the full intensity of the heat, will be found fused into a kind of slag, or clinker, and must be reckoned amongst the refuse. The loss from this cause is greater, as these clinkers and the neighboring bricks (which are also vitrified and vesicular on the surface) are firmly fused together and to the base of the clamp, whence they must be removed with crowbars, at considerable cost of labor, &c. Other bricks again, are vitreous on the surface, or glazed, others thoroughly baked, and towards the top of the kiln, or clamp, where the heat was least intense, the bricks are only half burnt. These different qualities may be distinguished in general by the color, the glazed or vitreous bricks being of a dark grayish-brown, the well baked red, while the half baked are yellowish-red, or yellow; the colors vary, however, in some degree, with the quality of the clay.

It is an important part of the brick-maker's business to sort the bricks as they are taken from the kiln or clamp, some being better adapted for certain purposes than others. Thus, for instance, hard-burnt bricks are employed for outside work, less baked bricks for the interior of buildings. The harder they are burnt, the more sonorous they become when struck, and *vice versâ;* hard-burnt, and glazed bricks last longer when exposed to frost than those which are less burnt, but they are not so well adapted for binding together with mortar, for which a rough and porous surface is required.

In Holland, where there is a great scarcity of stone of all kinds, semi-vitrified bricks, which show symptoms of fusion when broken, are very important as material for making roads. They are called there, *klinkerte*, and are arranged side by side on their edges in paving. Their density and hardness enables them to last where the frost and traffic would soon destroy ordinary bricks.

Form.—The shape of the bricks is adapted to the purposes for which they are intended; they are either wedge-shaped for arches or round chimneys, or in the well-known rectangular form for ordinary walls. It is, however, very convenient in building, when the thickness of the bricks is exactly equal to some fraction of the thickness and length, *i. e.* when a certain number laid one upon the other exactly corresponds with the thickness or length of one brick, or when the same is the case in breadth. This is necessary in order to give sufficient stability to the walls in building. The bricks are not laid one directly over the other in the walls, but alternately one over the join of two below it, as shown in Fig. 219.

Fig. 219.



Roofing-tiles, which are destined to a very different use, must consequently be of a different character; although these have no weight to bear, yet they are exposed to the full influence of the weather; they must, therefore, lie close without allowing water to pass between them, and yet *burden the roof as little as possible.*

Pressed Tiles.—The lightness of the roofing is influenced partly by the form of the tiles and partly by their weight. Very light tiles are generally porous, brittle, and more liable to be destroyed by the frost. It is a great point to give them a closer texture and make them thin at the same time, so as not to increase their weight. Porous tiles, in which the particles are not in close contact, are generally brittle, and if the porosity is obviated by fusion, there is great danger of their bending, and becoming still more fragile. The great porosity of ordinary tiles is due to the large quantity of water with which the clay is impregnated during the process of moulding, and which is subsequently evaporated in the kiln. Less moist clay cannot be worked with the hand. These practical facts have led to the plan of producing tiles by *pressure.* The clay employed for this purpose is only moist enough to acquire tenacity under a powerful press in a mould. The tiles formed are very much more dense, partly in consequence of the absence of water, and partly from the action of the press. A tile-press of this kind has been introduced and recommended by Henschel. It is somewhat more difficult to manage than the ordinary hand moulds, so that only about 600 roofing tiles can be moulded in a day. The time required for drying the pressed bricks and the space they occupy are very much lessened, the tiles being firm and inflexible as they leave the mould, and capable of being stacked up one upon the other. The advantage gained in lightness, particularly when the tiles are of the proper shape, will be obvious from the following comparison instituted by the Society of Arts at Mayence.*

One square fathom of roofing.	Costs.	Requires.	Which weigh.	Difference.
	s. *d.*	Tiles.	lbs.	lbs.
Of Henschel's tiles - - - - - -	7 1	96	576	249
Of ordinary tiles - - - - - -	9 3	300	825	

Pressed and glazed tiles are much more durable, as moss and other plants, which are amongst the most destructive agents, do not so readily take root in them as in porous clay tiles.

A comparison of a similar kind has been made at Vienna between ordinary bricks and those made by pressure in E. L. Müller's machine. In this case, the weight is not so much an object, as resistance to pressure. The bricks were laid upon two sharp blades, placed at a distance of 7 inches from each other, and weights were applied to a third sharp edge, pressing exactly on the middle of the bricks. It was found that:

* The ordinary tiles used weighed 2¾ pounds; those of Henschel, which were much larger, 6 lbs. a piece.

Müller's pressed bricks broke with a weight of 2,240 lbs. (mean of 24 trials).

Ordinary bricks broke with a weight of 1,530 lbs. (mean of 48 trials).

Glazed Tiles.—In Holland, tiles are covered with a coat of glaze, not merely for the sake of ornament, but in order to render them more capable of resisting the action of the weather. They are, of course, more expensive. The glaze is similar to that used by potters, and consists of minium, colored with manganese or oxide of copper. Yellow tiles are also made with sulphuret of antimony. The glaze is applied by dipping or sprinkling the air-dried tiles. Glazing is also practiced in France, as, for instance, at Dijon and Rheims.

Color of Bricks and Tiles.—The natural color of bricks and tiles is always connected with the amount of iron contained in the clay of which they are composed; this iron is either converted into the highest or red oxide; or the heat is insufficient to produce the full red color; or, lastly, a partial reduction occurs, and the iron is in the state of a mixture of the two oxides, when the bricks appear of an iron-gray color. In Holland, for instance, when the tiles are thoroughly baked, and at a full red heat, fresh brush-wood, together with the leaves (alder), is thrown upon the glowing peat ashes. A smoky flame is thus produced, which partly reduces the oxide of iron, but communicates a dark color to the bricks, chiefly by the deposition of charcoal.*

Stone Bricks.—There is a very peculiar brick, manufactured at Neath, in Glamorganshire, of the properties of which, however, the proprietors seem to be ignorant. The materials of which the brick is composed are brought from a quarry in the neighborhood. They are very coarse, being subjected to a very rude crushing operation under an edge-stone; and, from the size of the pieces, it is impossible to mould by hand. There are three qualities, which are mixed together with a little water, so as to give the mass some coherence, and in this state it is compressed by a machine into a mould. The brick which results is treated in the ordinary way, but it resists a much greater heat than the Stourbridge clay-brick, expands much more by heat, and does not contract to its original dimensions. Owing to this latter property, it has been found very valuable in constructing furnaces, more particularly the arches of the reverberatory furnaces employed at Swansea in smelting copper ores. The composition of the three materials is as follows:

	From Penderyn.	From Dinns.	
Silica	94.05	100	91.95
Alumina, with trace of oxide iron	4.55	traces	8.05
Lime and magnesia	—	traces	traces
	98.60	100	100.00

* In England, colored bricks have been manufactured by Mr. Barnes, and present a very beautiful appearance. Variegated tiles (tessera) are now made by Mr. Minton, of Stoke, and the latter also by Mr. Singer, of Vauxhall.

The bricks may, therefore, be said to be *siliceous* or *stone-bricks*, and there cannot be a doubt that, for the construction of many descriptions of chemical furnaces, such bricks would prove of essential service. In fact, when a good, clean sand-stone can be obtained capable of resisting heat, and the small broken pieces can be mixed in the process of quarrying with a little clay to impart tenacity, a very valuable fire-brick may be moulded from it.

The following is the analysis of a kind of red fire-brick, manufactured at Windsor, and of the clay from which it is prepared:

Windsor brick.—	Silica	84.65
	Peroxide iron	4.25
	Alumina	8.85
	Lime	1.90
	Magnesia	.35
		100.00 (Richardson).

The Windsor clay is a mechanical mixture of about

Sand	70
Clay	30
	100 (Richardson).

LIGHT OR SWIMMING BRICKS.

Character.—Burnt bricks, when composed of a certain quality of material, acquire such a degree of porosity, and become so light as to weigh very much less than an equal bulk of water. It is well known that silica, as it is obtained from the decomposition of the silicates, is remarkable for its loose nature and lightness, properties which it retains at a white heat, in consequence of its infusibility. When any kind of earth, consequently, contains a large quantity of porous silica, and bricks are formed from it, either alone or with the addition of a little clay to bind the particles together, these bricks will retain, in a great measure, the properties of the silica. These bricks combine great lightness with infusibility, and from the large quantity of air enclosed between their particles, are remarkably bad conductors of heat. They consequently form an invaluable building material wherever lightness (as for arches), fire-proof characters, or infusibility are desirable properties.

Posidonius, and subsequently Strabo, state that swimming bricks were composed of an earth found in Spain, on one of the islands of the Tyrrhenian Sea, and in other places. Vitruvius Pollio recommends them for building, and Pliny for their general usefulness. These swimming bricks, which had been entirely forgotten, were again manufactured by Giovanni Fabroni, in the year 1791, from an earth which is found near Santafiora, in Tuscany. The earth was composed of about 65 per cent. silica, 17 magnesia, 14 alumina, and 4

lime. These bricks swam on the surface of water, could not be sunk, were capable of binding with mortar, and were such bad conductors of heat that one end could be held in the hand while the other was red hot. As an experiment, Fabroni constructed the powder magazine of a ship with these bricks; the vessel was set on fire and sunk without exploding the powder. About the same time, Faujas, and in the year 1832, Count Fr. de Nantes, and Fournet, of Lyons, called attention to a similar kind of earth in France (at Ceyssat, near Clermont, and at Randanne, in Auvergne), which afforded bricks of precisely the same character. The earth described by Fournet was whitish-yellow, soft, like chalk, exceedingly fine, was not soluble in water, and could be worked with about $\frac{1}{20}$th of clay. It consisted, after being heated to redness, (losing water, organic matter, and carbonic acid,) of 87 per cent. silica, with 3 of alumina and oxide of iron.

The microscopic researches of Ehrenberg, in Berlin, upon these earths (particularly those of Ceyssat, Santafiora, and Zante), have led to the remarkable discovery, that they are entirely composed of an assemblage of the small microscopic silicious shells with which certain infusoria are covered. Ehrenberg concluded from this, that the clay composed of infusoria under Berlin, was also adapted to the production of similar bricks, and the result completely confirmed his expectations. This layer of clay is very extensive on the banks of the Spree, sometimes attaining a thickness of 100 feet; it consists of the silicious coats of infusoria, the size of which, individually, is not greater than the ninth part of the diameter of a human hair, and in the fresh state is dry, of a pearl-gray or white color. A cubic foot weighs, in the crude state, 61 lbs.; after elutriation and drying only 25 lbs. 7 ozs. Bricks composed of this earth only weigh about $\frac{1}{4}$ as much as ordinary bricks. The following observations have been made with bricks composed of this earth, prepared by different methods. Bricks 10 inches long, $4\frac{5}{8}$ inches wide, and $2\frac{1}{2}$ inches thick, comprising, therefore, 120 cubic inches altogether, were found:

	When prepared from	Of the following character.	And weighed. lbs.	oz.	Contraction.
	Infusorial clay suspended in water and slightly pressed	capable of being cut with the knife: soft, porous, reddish	1	11	—
In the tile-kiln.	Crude infusorial clay, not purified, slightly pressed	absorbent; hardness, that of a bad brick	3	—	—
	Infusorial clay with 5 per cent. of clay	ditto ditto ditto	3	5	—
	Infusorial clay with 10 per cent. of clay	harder	4	—	—
In the porcelain-kiln.	Crude infusorial clay, unprepared Infusorial clay with 5 per cent of clay Infusorial clay with 10 per cent. of clay	sonorous, absorb 1 lb. of water	as before		$\frac{1}{20}$

The same bricks, heated to whiteness for 6 hours, contracted still more ($\frac{3}{40}$ths), appeared of the color of cast iron, and produced sparks

with steel. Those containing 10 per cent. of clay, were used for building the Museum in Berlin.

The infusorial earth is an admirable cement for clay instead of sand.

FIRE-CLAY WARES.

These wares are employed either for smelting, as *crucibles*, or as bricks, for lining smelting and other furnaces, *fire-bricks*.

It would be a great mistake, in speaking of technical subjects, to confound the idea of *fire-proof* with what is scientifically termed *infusible*. Fire-proof is only a relative term, and implies infusibility at the certain temperature mentioned in connection with it. A brick may consequently be fire-proof in a lime-kiln, which could not withstand the heat of a porcelain-furnace, and substances which are perfectly capable of standing all the degrees of temperature employed in manufactories may be melted and frequently volatilized before the oxyhydrogen blow-pipe, or between the poles of a galvanic battery. Thus, pure silica, for instance, has been fused in the latter flame, like glass, and drawn out into fine threads. The success of smelting and other operations, in which very high temperatures are required, and the economical advantages derived from them, are so intimately connected with the materials employed in building the furnaces and implements, that a general explanation of this subject becomes imperatively necessary.

The degree of fusibility which a substance possesses, is mainly dependent upon its chemical nature, and quite as much upon its elementary composition, as upon its constitution. In other words: fusibility is not solely influenced by the elements which enter into the substances and the proportions in which these are contained in it, but also upon the manner in which they are arranged or combined with each other. This question has been enlarged upon at pages 220 and 256, with reference to the nature of porcelain; and the introduction to the article on glass, considered the conditions essential to the fusibility, &c. of the silicates, which conditions also apply here in full force. It appears, therefore, that the property of easy fusibility is dependent, on the one hand, on the nature of the bases, (alkalies, earths, and metallic oxides); and on the other, in a still higher degree, upon the relation of weight existing between these and the silicic acid. The chief constituent of the clays, alumina, is a base which, in combination with silica, forms one of the most refractory substances, and imparts this property to the clays in proportion as they are unmixed with other bases, as alkalies, oxide of iron, lime, and magnesia, in the order they are here arranged. In the purer varieties, or nearly pure clays, which are fire-proof with reference to all technical purposes, the refractory quality is augmented in proportion to the quantity of silica which they contain, and acquires a maximum in those substances bearing the strongest outward resemblance to the clays, but which can hardly be classed with them, on account of

the large quantity of silica that enters into their composition; such, for instance, are the varieties of *rottenstone*, consisting of the remains of infusoria.

As an example from practice, the following comparison sufficiently explains why the clay in question cannot possibly be fire-proof in a glass-furnace; for,

It contains	Silica.	Alumina.	Magnesia.	Lime.	Oxide of iron.	Potash.
Clay from the Isle of Bourbon	100	34.1	0.2	2.2	66.2	trace
French bottle-glass	100	30.7	—	61.6	13.4	13.4

When, therefore, it is desirable to procure fire-proof materials, a chemical analysis, although it cannot supersede an actual trial, may be of the greatest service, as the clays seldom or never come up to what is required of them, and only acquire the requisite properties by certain additions, and the choice of these additions must in the first instance be guided by the results of the chemical analysis. Such additions are absolutely necessary, as fire-clay must not only be infusible in the fire, but must likewise not be subject to crack and fly. These properties are most important in the case of crucibles. The chief cause of the cracking, or the *contraction* of the clay, must therefore be lessened by the addition of substances which do not shrink themselves, and, on the other, do not impair the refractory nature of the clay. Pure sand (free from lime and iron), and ground, previously burnt fire-clay, are the substances most commonly and appropriately used.

Everything that has yet been stated, refers especially to the case in which the fire-proof ware is exposed alone to a high temperature; but the conditions are essentially different when fire-clay is brought into contact with substances which exert a chemical reaction upon it, decomposing it and acting as a flux. It is then still more difficult to obtain a ware that will withstand the combined action of heat and chemical affinity.

Hessian Crucibles.—The well-known Hessian crucibles from Almerode, are prepared with half their weight of sand, which prevents them from cracking, and the clay of which they are composed is in itself very infusible; as soon, however, as substances are heated in them which contain fixed bases, as alkalies, their refractory nature is jeopardized, as these bases combine with the sand, and form fusible silicates. Oxide of lead fused in one of these crucibles, often penetrates through the sides and bottom. The sand in this case, therefore, is an addition which diminishes the contractibility and consequent liability to break at a high temperature, but at the same time increases the fusibility of the substance. Under such circumstances, the addition of ground fragments of previously burnt clay (*sherds*) is preferable. Very dense and difficultly burnt coal, as graphite or coke, may also be used, and combines the properties of chemical inactivity and perfect infusibility; graphite is particularly applicable, as it is not

consumed in an ordinary crucible furnace. The crucibles from Passau or Ipser are made from 1 part plastic clay from Schildorf, near Passau, and from 2 to 3 parts of an impure graphite, also found in the same neighborhood, in nests, layers and veins, traversing the gneiss. This graphite is composed, according to Berthier, of:

Carbon	34
Silica	41
Alumina	15
Oxide of iron	8
Magnesia, Water	2
	100

The graphite is ground and sifted before being used. The Ipser crucibles can be heated to a temperature of 150° Wdg. without undergoing alteration; they withstand changes of temperature exceedingly well, and are preferable to any other kind, in consequence of the smooth surface which the graphite communicates to them, and which enables the melted metal (for castings, money, &c.) to be poured from them in an uninterrupted stream, without leaving any particles behind. The Ipser crucibles, however, are too expensive for all those purposes which require that the crucible should be broken after each, or is rendered useless for a second operation. Crucibles that contain too much coke or an excess of cement (*sherds*) are frequently so porous as to become permeable to easily liquid matters, without the concurrence of any chemical action.

Constituents.—As a general rule, however, crucibles soon become useless, and it is an exceptional case when they last 20 meltings, as in the iron-foundry of Berlin. The chemical action of the substances in process upon the fire-proof vessels and utensils is not so prominently perceptible in cases where fire-bricks are employed, and is confined here to the action of the vapors (p. 41) and the ash mechanically brought into contact with them. The most noted fire-clays employed in the construction of crucibles and bricks are collected in the following table, with the results of the chemical analysis of them:

Dried at 100° C.	Gross Almerode.		Beaufois, Dep. des Ardennes.	Brierley Hill, near Stourbridge.		Schierdorf, near Passau.
	Berthier	Salvetat.	Berthier.	Berthier.	Salvetat.	Salvetat.
Hygrometic water	—	0.43	—	—	—	0.50
Combined water	15.2	14.00	19.0	10.3	17.34	16.50
Silica	46.5	47.50	52.0	63.7	45.25	45.79
Alumina	34.9	34.37	27.0	20.7	28.77	28.10
Oxide of iron	3.0	1.24	2.0	4.0	7.72	6.55
Lime	—	0.50	—	—	0.47	2.00
Magnesia	—	1.00	—	—	—	—
Alkali	—	trace	—	—	—	—

The following are the analyses by Mr. C. Cowper of the fire-clay employed at Birmingham in making glass-pots:

	In the dry state. Best Stourbridge pot clay.	Clay from Monmouth.	In the ordinary state. Best Stourbridge pot clay.	Monmouth clay.
Silica - - - - -	70.6	80.1	63.3	75.3
Alumina - - - - -	25.9	17.9	23.3	16.8
Oxide of iron - -	2.0	1.0	1.8	1.0
Carbonate of lime -	1.5	1.0	1.3	0.9
Carbonate of magnesia	trace	—	trace	—
Water - - - - -	—	—	10.3	6.0
	100.0	100.0	100.0	100.0

Vessels composed of fire-clay must generally be more strongly fired, in order to acquire an equal degree of solidity, than common clay-wares; this is partly occasioned by the large quantity of cement which enters into their composition. It is of the greatest importance that fire-bricks should have acquired their greatest amount of hardness, and have contracted to the full extent, before they are used. In the case of crucibles, firing is not always necessary; while the Passau crucibles are brought into commerce only in a dried state, the Hessian crucibles are burnt at about the same heat as ordinary stone-ware.

For the knowledge of the elementary composition of, and the relative proportions of the constituents in, several kinds of smelting crucibles, we have to thank Berthier.

The following are the results he obtained:

Place of manufacture.	Silica.	Alumina.	Oxide of iron.	Magnesia.
Crucibles from Gross Almerode - - - - -	71	25	4	—
" " Paris (Beaufays) - - - - -	65	34	10	—
" " Saveignies, near Beauvois - - -	72	19	4	—
" " England, for casting steel - - -	71	23	4	—
" " St. Etienne, for casting steel - -	65	25	7	—
Glass pots from Nemours - - - - - -	67	32	1	—
" " Bohemia - - - - - - -	68	29	2	trace

Clay Gas-retorts.—The retorts for the production of gas are, in conjunction with the glass-pots,* (compare page 35,) perhaps the largest vessels at present constructed of fire-clay. As there are many points of interest connected with their manufacture, we will describe the plans adopted by Cowen, of Newcastle-upon-Tyne. There are seven varieties of clay found in the neighborhood of Newcastle, all of which belong to the coal formation, and these furnish the material for the fire-proof wares; the clays occur below the coal, and are worked with them from the same pit; they are of a grayish-brown color, and full of vegetable remains. Dr. Richardson found in:

* The melting pots in the plate-glass works at Ravenhead are, with the hood, six feet high.

Nos.	1	2	3	4	5	6	7
Silica	51.10	47.55	48.55	51.11	71.28	83.29	69.25
Alumina	31.35	29.50	30.25	30.40	17.75	8.10	17.90
Oxide of iron	4.63	9·13	4.06	4.91	2.43 (oxide of iron and lime)	1.88	2.97
Lime	1.46	1.34	1.66	1.76		2.99 (lime and magnesia)	1.30 (lime and magnesia)
Magnesia	1.54	0.71	1.91	trace	2.30		
Water and organic matter	10.47	12.01	10.67	12.29	6.94	3.64	7.58

while the amount of silica in No. 6 is to the total amount of the bases, as 100 : 16, in No. 2 it is as 100 : 85. These clays are mixed in different proportions, according to the object of the manufacturer.

It is not usual to suspend the clay in water, all the coarser particles which in that case would be deposited, are consequently ground into the mass. Another important addition, is that of saw-dust, to the amount of about $\frac{1}{4}$th the weight of the whole. The gas-retorts must be capable of withstanding very sudden changes of temperature during the time they are charged and emptied, &c. In order to be durable, the thickness of the sides must be at least 3 inches. These circumstances, combined with the ⌂ form of the retorts, would inevitably cause them to crack, if the mass were not rendered excessively porous by the saw-dust, which is completely destroyed in the firing. Powdered coke is used for the same purpose. A loss of gas from the porosity of the retorts need not be apprehended, as the inner surface soon becomes covered with a layer of carbon.

The retorts, which are 7 feet long, and 2 feet high, are either moulded by hand from the mass, uniformly mixed with all the additions, in which case the walls are gradually built up, according to two wooden guides, the one of which indicates the thickness, the other the outward shape of the retort; or they are pressed in the machine represented in Figs. 220, 221, 222.

Fig. 220.

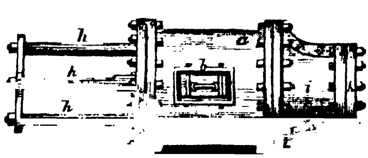


Fig. 221.

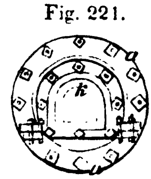
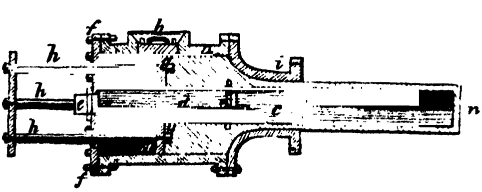


Fig. 222.



The iron cylinder, *a*, *a*, can be filled with clay through the close door, *b*. A hollow iron cylinder, *d*, is fastened to the bottom plate, *f*,

at *e*, and is drawn out in the form of a ⌓ at the front extremity, *c*, which enters the mouth-piece, *i*, and corresponds with the internal diameter of the retort. When the movable plate, *g*, *g*, is pressed against the clay from behind, this is forced into the space between the mouth-piece, *i*, and the end of the cylinder, *c*, and leaves the machine in the form of the retort. The clay is forced forward by causing a powerful hydraulic press to act against the movable rods, *h*, *h*, *h*, in the bottom plate, *f*. The back of the retort, *n*, is moulded simultaneously in the same machine. The closing-plate, *k*, (Figs. 220, 222), is placed in front of the mouth-piece, *i*, and the clay is pressed firmly against it before it is removed, for the formation of the retort. The bottom end is thus moulded in the space between *c*, and *k*. The plate, *k*, is then removed, and the press is allowed to work until the retort has acquired the proper length. The retort in process naturally issues from the aperture, *i*, much more rapidly, in consequence of its small diameter, than the plate, *g*, approaches the mouth-piece. The resistance of the clay is so excessive, that the motion is hardly perceptible, and iron cylinders of from 2 to 3 inches in thickness have been torn asunder and unable to resist it. The drying and burning must proceed as slowly as possible, or the retorts are liable to burst when used. The firing lasts 14 days, and the burnt retorts are of a light yellow color.

If other shapes are required, the cylinder *c* can be exchanged for one of another form.

Fire-bricks.—An extensive trade is carried on near Newcastle-on-Tyne in the manufacture of these bricks. The clays used are the same as those of which the composition is given above, and the preparation of which is as follows:

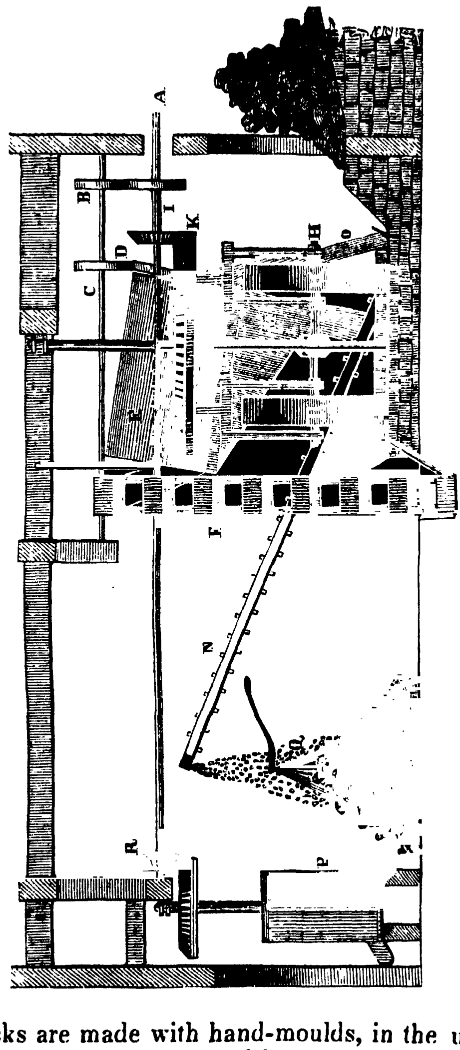
The fire-clay, after exposure to the atmosphere for some time, is removed to the clay-mill, where it is ground up with fragments of the same clay, previously baked. Manual labor is saved as much as possible. The sketch, Fig. 223, gives a general idea of the arrangement ordinarily adopted for this purpose, with the exception that in some cases, the bed-plate is made to revolve instead of being a fixture, as shown in our drawing.

G represents the rough clay, conveniently placed for the workman to cast under the edge-stones, when it is ground to a coarse powder, which falls down through the opening, *L*, in the bed-plate, whence it is lifted into the cylinder, *E*, by means of the endless chain of buckets, *F*. The clay as it passes down the cylinder is separated into two parcels, the fine falling through the case, *M*, and the coarse being received in the spout, *O*, which delivers it under the edge-stones, to be ground again. The fine is carried on an endless belt, *N*, to a convenient spot, where, as it falls to the ground, it meets a continuous stream of water, as at *Q*, a workman roughly mixes it for the pug-mill, *P*, or in some cases it is delivered at once from *N* into the pug-mill, *P*.

The shaft, *A*, driven by steam or water power, communicates motion to the edge-stones by the wheels, *I*, *K*, and to the pug-mill, by the bevel-wheel, *R*. A belt, *B*, drives the shaft, *C*, which communicates

motion to the cylinder, *E*, by another belt, *D*, and to the buckets, *F*, directly. The endless belt, *N*, receives its motion from the same shaft. The contrivances for collecting the clay on the *bed-plate*, and throwing it under the stones, are also not indicated, as they are well known, and the only object of the drawing being to give a general idea of the nature of such arrangements.

Fig. 223.



The fire-bricks are made with hand-moulds, in the usual manner, from the prepared clay. A man and boy mould and lay down to dry on the flat 1500 bricks for 3*s*. 8*d*. (=93 cts.) They are dried on a warm place, and burnt in the kilns represented in Figs. 224, 225, and 226. The kilns are about 15 feet long by 14 feet broad and 10 feet high, and hold about 15,000 bricks. The bricks are burnt for 5 days, during which time 5 tons of coal are consumed.

Fig. 224.

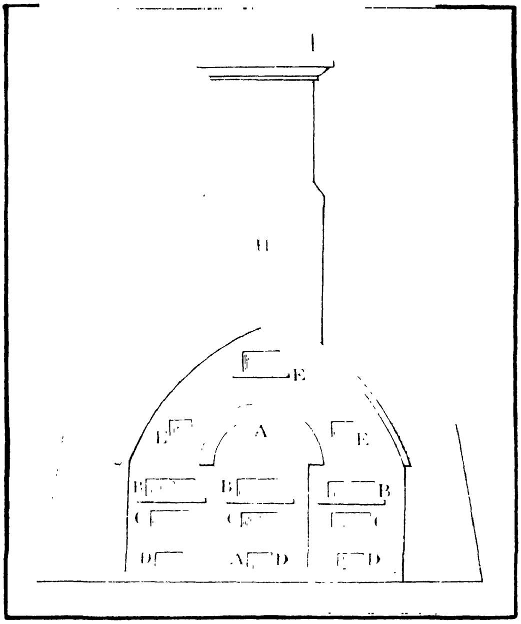


Fig. 224 is the front end elevation of the kiln.

Fig. 225.

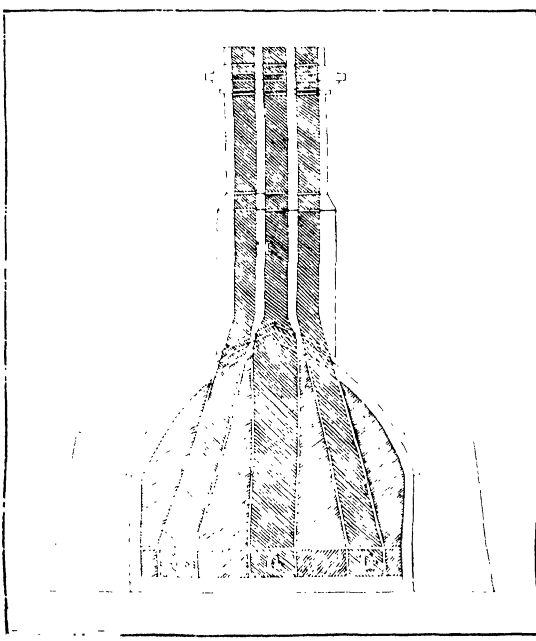


Fig. 225 is a section of the back of the kiln, and shows the position of the flues.

Fig. 226.

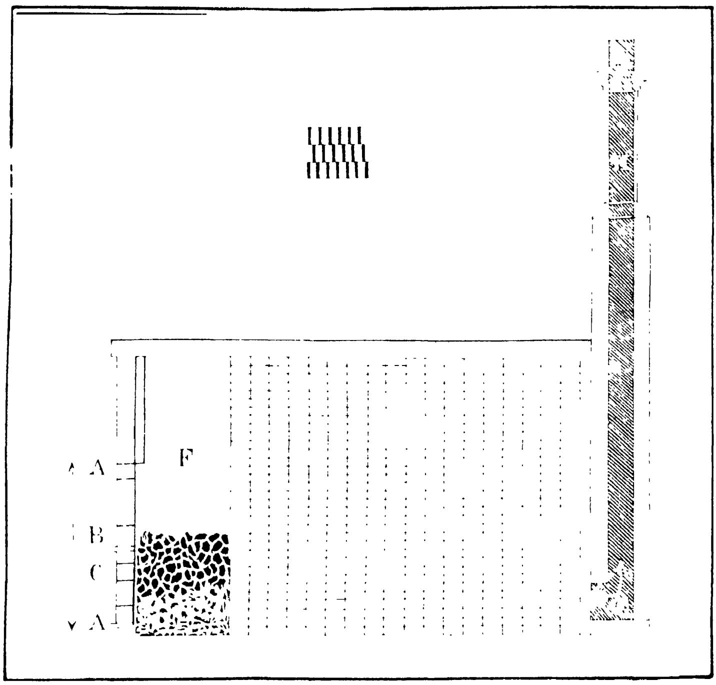


Fig. 226 is a longitudinal section of a kiln filled with bricks ready for firing.

The shaded part, *A*, *A*, is only temporary, being the opening by which the kiln is filled and emptied.

The openings, *B*, *B*, *B*, are for the purpose of charging the kiln with the fuel which is stirred up from time to time through the doors, *C*, *C*, *C*, while the ashes are removed from below by *D*, *D*, *D*.

The openings, *E*, *E*, *E*, are left for the workmen to regulate the heat, and watch the progress of the burning.

A space of about 4 feet, *F*, is left between the bricks and the wall of the kiln for the fuel.

The flame and hot air pass through the bricks, and make their escape through the flues, *Q*, *Q*, *Q*, at the end of the kiln into the chimney *H*.

The bricks are placed lengthways in the kiln, on their edges or sides, so that as seen in the section, Fig. 226, they appear closely packed, but in looking at them from the end, they are separated by each other about a finger's breadth, as shown at the top of Fig. 226.

GROUP IV.

OF LIME, MORTAR, GYPSUM, MAGNESIA, BARYTES, &c.

Importance of Lime in the Arts.—Lime (CaO), or, more strictly speaking, the combination of lime with water, *hydrate of lime*, or slaked lime (CaO,HO), is a substance which is most extensively used in the arts, on account of its powerful chemical action and low price.

The great use of this substance is mainly attributable to two causes. First, lime possesses, in the state of hydrate, the property of combining with acids and with substances of an analogous nature; a property which ranges it amongst the most powerful bases after the alkalies.

It is, chemically speaking, a valuable reagent, and of paramount importance in the arts, because, and this is the second point, it is *easily* obtained in *every* locality. The lime-stones, consisting principally of carbonate of lime (CaO,CO_2) which compose the raw material for the lime-kilns, are members of almost every geological formation, and constitute a considerable portion of the surface of the globe. Carbonate of lime parts with its carbonic acid at a moderate red heat, and becomes *caustic* or *burnt lime* (CaO), which, when brought into contact with water, is slaked, or enters into combination with it (CaO,HO), falling, at the same time, into an impalpable powder,—(it is well known that the union of lime with water does not deprive the lime of its causticity, but rather tends to call this property into full activity.)

The technical value of burnt lime is, therefore, due to its powerful basic properties, to the facility with which it can be everywhere obtained, and to its low price, its value is also much augmented by the manner in which it is reduced to a fine state of division by water, without which its usefulness would be much restricted.

The pulverulent form of lime is a condition rendered more essential in consequence of the sparing solubility of the substance in water (a property that distinguishes it from the alkalies, to which it would otherwise be equal in chemical activity). The solutions of lime are so dilute and weak as to be inapplicable for most purposes, and this renders the use of lime in mass essential, and its fine state of division the more necessary.

These general observations with reference to the importance of

lime, can easily be elucidated by examples from practice. The smelter employs lime as the base with which to unite his silica and form a flux or slag; the manufacturer of stearine employs the basic property of lime to unite with and separate the fatty acids from the natural fats. The soda-maker decomposes sulphuret of sodium; the soap-boiler, the carbonate of soda in his ley, by means of the more powerful agency of lime; the property which lime possesses in common with the other bases of absorbing chlorine, renders it applicable to the manufacture of bleaching-powder, &c.

Application of Lime.—In the preceding sections numerous applications of lime have been described; in those which follow, they will not be found less numerous. In the present chapter, only those technical applications of this base will be noticed, in which it is not merely a means to the attainment of some end, but in which it is employed as the chief and essential material, as in *building*, and for the production of *mortar*. By mortar, we understand a mixture of lime with certain substances, which impart to it the property of hardening and becoming stone, and which are used as cement in binding bricks and stones together.

This hardening and conversion into stone, is partly due to the influence of the air, and does not occur under water, and is partly, on the other hand, solely attributable to the agency of water. Both cases are dependant upon such very different chemical causes, the nature of the material is in both so different, and lastly, their application is so perfectly distinct, that the subject naturally calls for attention under two separate heads; these are

Ordinary lime (*Luftkalk*) and *mortar*,
Hydraulic lime and *mortar*.

OF COMMON LIME.

From what has been stated, and from the fact that caustic lime is one of the most rare productions of nature, it will be obvious that those combinations of lime must be sought and employed for technical purposes which are the most generally diffused and easy of access. Carbonate of lime is the substance, already noticed as forming the principal ingredient of all natural limestones, which is everywhere employed for this purpose, (with the exception of gypsum, which is much less abundant, and of which we shall speak below.) The limestones may be classified, from their outward mineralogical characters, under the following arrangement:

Granular limestone with a decidedly crystaline grain: the different varieties of marble, (Parian, Carrara,) and particularly the old mountain-limestone, belong to this class. The limestone from Auerbach, in the valley of the Upper Rhine, and most of the other varieties, occur in veins, *i. e.* they fill up broad fissures in the granite, and appear to have been forced from below, upwards. It frequently encloses mica, fluorspar, silicates, &c.

Compact limestone occurs in quite as great a variety of colored species as the foregoing, but is never so white. It is found in all geological formations, and is named according to its age, or from the formations of which it is a member; we thus have: transition-limestone, greywacke-limestone, carboniferous-limestone, mountain-limestone, shell-limestone, (muschelkalk,) Jura-limestone, lias-limestone, fresh-water-limestone, &c.

Limestone Breccia, consisting of lumps of limestone, cemented together by another limestone mass.

Limestone marl, more or less uniformly mixed with clay, of a dense earthy fracture. This and the foregoing variety belong to no particular member of the stratified rocks, exclusively.

Silicious limestone contains numerous silicious minerals, as quartz, hornstone, chalcedony, opal, &c. This variety is dense, and interspersed often with cavities; it is gray or yellowish-white.

Stinckstone, or *fetid limestone*, is characterized by the bitumen which it contains, and which is rendered perceptible to the smell by friction. It is generally dense, and exhibits stratification. It is called *friable marl* (*Asche* by German miners) when it occurs as a disconnected earthy mass, and is of a dark color.

Chalk is a dense, earthy rock, imparting color when rubbed, seldom other than of a white color. It is distinguished as being the matrix of flints. Chalk is remarkably developed on the shores of the Dover Straits and on the island of Rügen. It belongs solely to the formation whose name it bears.

Coarse lime is dense, earthy, approaching sandstone in appearance, and contains a large proportion of quartz-sand and clay. It belongs to the Molasse-formation, and is stratified.

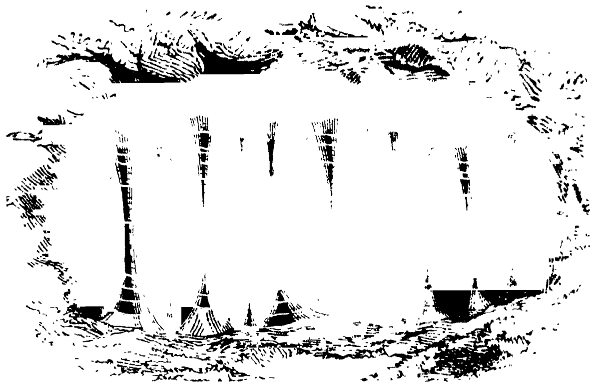
Calcareous tufa consists of layers of lime which are pretty free from foreign matters, and is still in the process of formation. Generally unstratified. In some parts, it is loose, porous and earthy; in others dense, passing into a variety of dense limestone.

Calcareous tufa and Travertin belong to this class. Lime of similar origin is called calcareous sinter when the stratification contains crystaline particles (calcareous spar or arragonite), arranged like layers of bark, one above the other, often in the form of columns, (Tropfstein.)

These formations are produced by the solvent action of water containing carbonic acid upon carbonate of lime.

The *stalactites* and *stalagmites*, shown in Fig. 227, which frequently cover the roofs and floors of certain caverns, are also due to the same cause. The water which permeates the rocks above them, dissolves the carbonate of lime, by reason of the carbonic acid which it contains. In dropping from the roof, however, it remains suspended for some time, and, losing a certain part of the acid, deposits also a portion of the carbonate of lime, previously held in solution. The accumulation of these minute portions of lime gradually form the stalactites. The same takes place on the floors of the caverns, giving rise to the formation of the stalagmites.

Fig. 227.



Dolomite is characterized by a large amount of magnesia; it is generally granular, and seldom earthy or massive. It is not distinctly stratified, but sometimes bituminous.

The characters of limestone which stand in connection with the theory of the earth's formation, or the geological characters, lead to a totally different classification. Limestones which hardly differ in external characters, and cannot be distinguished from each other, may belong to very different formations, and *vice versâ*. The examination of a limestone in one point of view only, must therefore lead to a very imperfect knowledge of its nature. The mere study of its chemical constitution, would also afford but a very partial means of judging it. When the mode of occurrence, the extent and the relations of stratification of the limestones are considered in connection with their other characters, conclusions may then be drawn concerning the mode of their formation, and it is probable that very interesting results would arise from such a comparison, showing the connection between the mineralogical and chemical characters of the limestones, and the causes which have concurred in their production.

Many limestones, as that near Auerbach, exhibit clear indications of having been put in motion in the liquid state. Limestone of this kind must possess a high degree of purity, as, if this were not the case, (and clay or other substances were present,) the result of the fusion would certainly have been different, and would not have ended in the formation of crystals of pure carbonate of lime.

Other limestones, which have been formed by precipitation from soluble salts of lime, are more likely to contain foreign admixtures, which have been deposited by chemical or mechanical agency. Thus, some contain magnesia, iron and manganese uniformly disseminated through them, others are mixed in the same manner with aluminous or silicious particles, or these are interstratified with them.

Others, again, and a whole series of limestones, have obviously been formed with the concurrence of the animal creation, and it is of importance to ascertain what part the living beings have performed

in this general development. Thus, at the present moment, whole islands are being raised up in certain latitudes and oceans, from the calcareous coverings of the coralline animals, just as in former ages the range of the Jura and other mountains have been produced from the same agency. There are likewise limestones, as the shell limestones, which are composed of masses of shells of crustaceous animals. The shells of these animals have been filled with lime, and cemented together so as to form a more or less solid rock. The bodies of the animals have not, however, disappeared without leaving a trace behind them; for, that which is denominated *bituminous* in these rocks, is generally the residue of decomposed animal matter permeating the entire mass of the stone.

Ehrenberg has also shown that the chalk, independent of the larger fossils, Belemnites, &c., is composed of the calcareous panzers of Polithalamia, with a small quantity of the silicious shells of infusoria. It has, therefore, been condensed by the vital powers of these microscopic animals in building their shells from the soluble lime contained in the water in which they existed.

While many of these limestone formations have been deposited from sea-water, others appear to have been decidedly formed in fresh-water. Calcareous tufa is still being deposited in numerous places from springs, the carbonic acid in which, under greater pressure, dissolves lime, which is again precipitated, when the carbonic acid is evolved under the lesser pressure of the atmosphere.

With reference to the chemical differences in the limestones, these stand in a certain relation to their respective sources, and are very important in determining their application and value.

The composition of several of these varieties is given in the tables below:

Origin of the limestones.	Calcareous spar from Andreasberg.	Coarse grained limestone from Paris.	White granular limestone from Drebach.	Chalk from Bougival.	Yellowish-gray limestone from near Lyon.	Freshwater-limestone from Vichy.	Shell-limestone (Muschelkalk), from Hollenhagen.
Analysts.	Stromeyer.	Berthier.	Kersten.	Laurent.	Berthier.	Berthier.	R. Brandes.
Carbonate of lime	99.54	98.5	96.30	95.50	94.0	87.2	83.83
" magnesia	—	—	2.42	0.80	1.6	10.0	1.76
" protox. of iron	—	—	0.72	0.80	—	—	—
" protox. of manganese	—	—	0.40	—	—	—	—
Silica	—	—	—	—	—	—	10.66
Alumina	—	—	—	—	—	—	0.03
Oxide of iron	0.36 (with oxide of manganese)	1.5	trace	1.70	3.9	2.8	1.73
Oxide of manganese		—	—	—	—	—	0.06
Water	0.10	—	—	1.20	—	—	1.93
Organic matter (Bitumen)	—	—	—	—	—	—	—
Number	1	2	3	4	5	6	7

Origin of the limestones.	Freshwater-limestone from near Paris.	Dolomite from Liebenstein.	Dolomite from Villefranche.	Dolomite from Spezzia.	Dolomite from Scheidama.	Dolomite from Dep. de la Dordogne.
Analysts.	Berthier.	Wackenroder.	Berthier.	Laugier.	Göbel.	Vicat.
Carbonate of lime	74.5	63.87	60.9	55.36	53.50	50.6
" magnesia	23.0	33.24	30.3	41.30	41.50	42.0
" protox. of iron	—	0.91	3.0	2.00	1.50	—
" protox. of manganese	—	0.07	6.0	—	—	—
Silica	—	—	—	0.5	(2.7 insoluble residue.)	5.0
Alumina	—	—	—	—		2.0
Oxide of iron	1.2	—	—	—		0.4
Oxide of manganese	—	—	—	—		—
Water		—	—	—		—
Organic matter (Bitumen)		1.05	—	—		—
Number	8	9	10	11	12	13

NORTHUMBERLAND AGRICULTURAL LIMESTONES.—COLBECK.

(PRINCIPALLY MOUNTAIN LIMESTONES.)

	Hartington.	Kirkheaton.	Belsay.	Allerwash.	Dryburn.	Oxford.	Stamfordum.	Acre.
Lime	34.0	27.4	39.0	49.39	38.5	42.8	52.0	37.9
Magnesia	.6	4.4	1.4	—	—	—	—	—
Insoluble matter, &c.	1.3	2.2	3.0	2.4	1.0	3.6	3.3	5.1
Carbonic acid and water	63.5	65.7	56.6	49.0	60.5	53.6	43.5	57.0
	99.4	99.7	100.0	100.79	100.0	100.0	98.8	100.0

MAGNESIAN LIMESTONES FROM THE COUNTY OF DURHAM.—JOHNSTONE.

	Garmondsay.	Stoney Gate.	Fulwell.	Seaham.		Hartlepool.	Humbledon Hill.		Ferry Hill.
Carb. lime	97.5	98.00	95.0	96.5	95.0	54.50	57.90	60.41	54.10
Carb. Magnesia	2.5	1.61	2.1	2.3	1.3	44.93	41.80	38.78	44.72
Alumnia ox. iron, &c.	trace	0.27	0.3	0.2	0.2	0.33	?	?	1.58
Insoluble matter	trace	0.12	2.6	1.0	3.5	0.24	0.28	0.81	4.60
	100.0	100.00	100.0	100.0	100.0	100.00	99.98	100.00	105.00(?)

MAGNESIAN LIMESTONES AFTER BURNING.—*RICHARDSON AND °HOLMES.

	°Ripon.	°Knaresborough.	*Fulwell.	*Bolden.
Lime	71.125	72.0	62.80	80.64
Magnesia	25.625	25.5	32.75	11.31
Ox. iron, alumina, &c.	1.750	1.0	2.30	6.05
Insoluble matter	1.500	1.5	trace	
Water	—	—	2.15	2.00
	100.000	100.0	100.00	100.00

MAGNESIAN LIMESTONES.—RICHARDSON.

	Near River Tyne.		Sunderland.		Rothbury.(?)
Lime	28.75	54.65	28.75	53.25	30.73
Magnesia	19.00	0.75	20.70	1.05	14.55
Alumina and oxide iron	0.75	0.45	3.15	1.15	4.41
Insoluble matter	4.85	—	trace	1.60	7.10
Carbonic acid and water	45.00	44.50	47.75	43.80	43.21
	98.35	100.35	100.35	100.85	100.00

MOUNTAIN LIMESTONES, &c.—RICHARDSON.

	Shotley Bridge.	Hareshaw.		Kilbride.	Portugal.	
Lime	44.43	32.31	54.88	49.68	51.86	48.11
Magnesia	1.27	trace	trace	1.26	2.00	2.76
Alumina and oxide of iron	1.15	4.59	trace	4.51	0.29	4.45
Insoluble matter	—	29.65	1.55	2.12	—	2.50
Carbonic acid and water	42.59	34.02	43.85	42.81	44.49	41.03
	89.44	100.57	100.28	100.38	98.64	98.85

MOUNTAIN LIMESTONES.

	Durham.* Stanhope.		Scotland.† Broxburn.		Blair-Adam.	United States.‡ Hudson River.
Carbonate of lime	95.06	93.77	56.32	62.72	60.63	45.30
Carbonate of magnesia	2.46	.37	2.14	7.89	13.19	25.70
Alumina, oxide iron, &c.	1.00	3.87	3.76	4.96	8.71	11.38
Insoluble matter	1.32	1.59	36.10	22.24	16.14	15.37
Water	—	—	1.90	0.98	0.30	2.25
	99.84	99.60	100.22	98.79	98.97	100.00

CUMBERLAND LIMESTONES.

	Cockermouth.	Brampton.	Relhead.	
Carbonate of lime	94.86	94.56	95.95	
Sulphate of lime	0.23	0.32	0.24	
Phosphate of lime	—	0.33	—	
Carbonate of magnesia	1.26	2.32	0.54	
Alumina and oxide of iron	0.73	1.18	1.21	
Silica	2.92	1.29	2.06	
	100.00	100.00	100.00	Johnstone.

* Johnstone. † Fromberg. ‡ Beck.

CHALK LIMESTONES, BY RÖMER.

	Maestricht.	Osnabruck.	Kromsberg.	Rethen.
Carbonate of lime .	96.5	26.0	86.5	85.5
Carbonate of magnesia	1.0	—	—	0.5
Alumina and oxide of iron	0.5	7.0	4.0	3.0
Silica . . .	0.5	59.0	5.5	6.0
Water . . .	1.5	8.0	4.0	5.0
	100.0	100.0	100.0	100.0

LIMESTONES AND MARLS FROM NEAR LYNN, AND OTHER LOCALITIES IN NORFOLK.—RICHARDSON.

Lime	33.90	41.50	33.90	46.44	45.40
Magnesia . . .	—	trace	5.85	—	—
Oxide of iron and alumina	7.40	4.65	6.45	trace	4.55
Clay	29.35	14.15	17.45	8.22	5.25
Carbonic acid and water	29.05	40.05	36.00	41.46	43.00
	99.70	100.35	99 65	96.12	98.20

COMPOSITION OF SCOTCH LIMESTONES.—JOHNSTONE.

	Argyleshire.					Berwickshire.				Inverness-shire.	
	Ardour. 1	Ardour. 2	Contyre.	Ban.	Glenhurvie.	Langton. 1	Langton. 2	Langton. 3	Langton. 4	Beauly. 1	Beauly. 2
Carbonate of lime . . .	90.14	89.15	98.05	90.96	46.33	43.85	47.00	39.01	43.81	93.82	94.10
Carbonate of magnesia .	0.31	2.56	0.44	0.62	29.68	33.34	38.04	30.25	39.50	1.64	1.00
Alumina and oxide of iron	0.51	0.51	0.29	1.81	11.64	1.59	1.99	1.39	3.57	0.99	2.16
Siliceous matter	9.08	7.48	1.27	6.40	11.95	21.41	12.97	29.27	13.09	3 55	2.74
	100.04	99.70	100.05	99.79	99.60	100.19	100.00	99.92	99.97	100 00	100.00

ASSYNT, SUTHERLANDSHIRE.

Carbonate of lime . .	49.92
Carbonate of magnesia .	36.23
Ox. iron and alumina . .	4.70
Siliceous matter . . .	7.92
Alkaline salts . . .	.20
Gypsum	.27
	99.24

STIRLINGSHIRE, BOQUHAN.—THOMSON.

	1	2	3
Carbonate of lime . .	53.09	56.07	53.06
Carbonate of magnesia .	43.49	39.34	43.11
Phosphate and perox. iron	0.96	0.74	2.34
Silica and alumina . .	2.46	3.85	1.49
	100.00	100.00	100.00

STIRLING, MURRAY'S HALL.—SINCLAIR.

Carbonate of lime . .	93.32	97.80
Peroxide of iron . .	2.79	0.63
Coaly matter . . .	0.28	0.64
Silica and alumina . .	1.36	1.92
	97.75	100.99

BERWICKSHIRE, TWEED.—STEVENSON.

	1	2	
Carbonate of lime - - -	49.60		
" magnesia -	44.00		
Silica - - - - - - -	4.00		
Phosphate of iron - - -	—	0.74	0.727
Peroxide of iron - - - -	1.20		
Alumina - - - - - - -	1.00		
	99.80*		

The foreign substances, which constantly accompany the limestone, are of two distinct kinds, as will be seen from a glance at the first two tables. Firstly, the combinations of carbonic acid with protoxide of iron, protoxide of manganese, and magnesia, which bases are isomorphous with lime, form an interesting subject in connection with the probable mode of formation of the limestone rocks. Even in calcareous spar, in the perfectly crystaline mineral, therefore, a certain amount of carbonate of magnesia is present, which increases in different specimens, from a mere trace to an amount equal to that of the carbonate of lime (when the mineral is called dolomite), and, passing through various intermediate stages, the proportions expressed by the following formula are often attained, $CaO,CO_2 : 3MgO,CO_2$. That which has here been stated with reference to the mineral, applies in the same manner to the entire rock. It gradually passes from nearly pure carbonate of lime into dolomitic limestone, and its nature becomes very much changed in consequence. While pure burnt lime absorbs water with great avidity and occasions a great disengagement of heat, forming a dense very soft paste, or, as it is called, becoming *fat;* the limestones containing magnesia are poorer in proportion as they approach to the composition of dolomite. The oxides of manganese and iron which are so frequently found in the limestones, have probably been formed by the action of the atmosphere upon the protoxides of these metals.*

Besides the carbonates, the silica and alumina contained in the limestone rocks are also of interest. They exist in the most variable proportions, often combined in the form of clay, sometimes associated

* [It is hardly necessary to say to the American reader, that all the varieties of limestone exhibited in the above analyses, are found in one part or another of the United States. This will be fully verified by a reference to the numerous State Geological Reports, and also to the excellent "system of mineralogy" of Dana.]—AM. ED.

with magnesia, sometimes alone. The silica is often, but the alumina never, in excess, so that both remain undissolved in acids. Their presence is without any perceptible influence when they are present in small quantity; but when their amount exceeds 10 per cent., the limestones are slaked very slowly and with difficulty after burning, their affinity for water is diminished, and they are then applicable to very different purposes. Of these we shall have occasion to speak below under the head of hydraulic lime.

The bituminous portions and the water are of no importance in the applications of lime, as they are destroyed or removed in the kiln. To complete the preceding analyses it must be stated, that nearly all kinds of limestone, after burning and slaking, afford sulphate of potash and chloride of potassium (or the corresponding sodium compounds) to water. These salts, and probably also silicates of the alkalies, are doubtless contained in the limestones themselves; the amount of alkali has probably been overlooked in the analyses from its minute quantity, and not having been specially sought for, or, being in combination with silica, has been left with the clay and not discovered. The presence of potash in the aluminous portion has been proved by Fuchs, Kersten, and Kuhlmann; traces of phosphoric acid have been found by Fuchs, and by Kaiser; and lastly, traces of titanic acid by Fuchs and Kersten. The potash, it may be stated, is one of the principal causes of the beneficial effects of marl in agriculture.

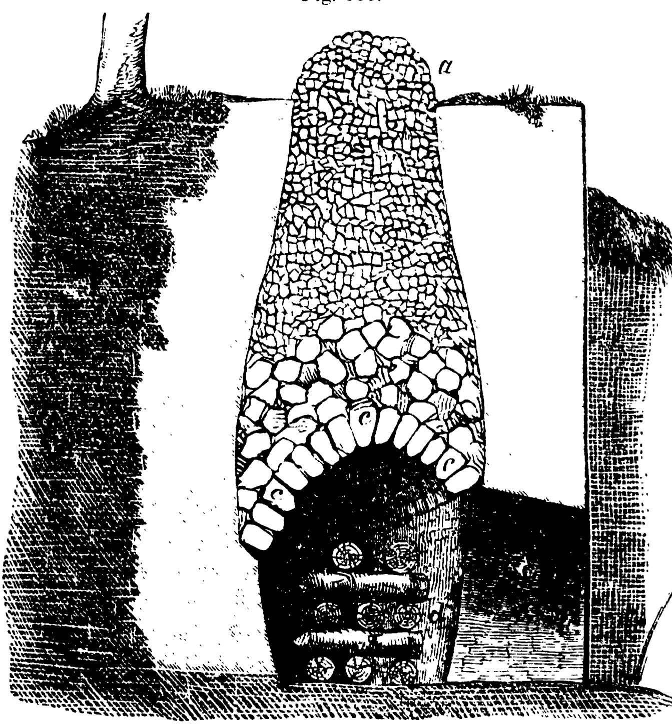
Lime Burning—Chemical Process.—Carbonate of lime is not decomposed at a low red heat, but is converted at a bright red heat into carbonic acid and lime. The temperature at which the decomposition is effected, is, however, influenced by circumstances, or rather depends entirely upon the facility afforded the carbonic acid for escape when it has been expelled from the lime. If the limestones are constantly surrounded with an atmosphere of carbonic acid, the further evolution of carbonic acid from them is, according to Faraday, very much impeded; but if the gaseous acid is removed as quickly as it is expelled from the lime, the process of removing the future portions of acid is much accelerated. In close vessels, the decomposition is stopped as soon as the space, not occupied by the lime, has become filled with carbonic acid. Hall found that pieces of carbonate of lime enclosed in a tube, and, consequently, under a high pressure, resisted decomposition in the porcelain kiln, and melted with a loss of, at most, 1 per cent., and thus solved the apparent contradiction alluded to in the theory of the primitive limestone. It was not immediately obvious why this limestone, which had been forced up in the melted state, should not have lost its carbonic acid at the melting temperature. After Hall's experiment, it is fully explained by the high degree of pressure under which the fusion occurred.

After these more general remarks, it will be proper to take in review the technical processes employed in burning lime, which must be viewed as a preparation of the limestone for its numerous applications in the arts. It has, indeed, already been indicated in the

foregoing section, that lime is occasionally burnt simultaneously with bricks; this, however, is only an exceptional case to the general practice, although the two processes are so far alike, as to be carried on, both by the most uneducated and needy laborers in the country, as well as by the most skilful manufacturers and capitalists in the neighborhood of large towns. All grades of perfection and variations in the process of lime-burning are consequently met with, of which the following examples are intended to give a summary idea.

Lime-kilns at Rodheim.—One of the simplest, but at the same time rudest arrangements, is that adopted in the neighborhood of Giessen (near Rodheim), in which the dense (transition) limestone found in that locality is burnt. The kiln, Fig. 228, is perpendicular, and

Fig. 228.



constructed of the same limestone (in the dry state and without mortar) as that which it is intended to burn. It is placed at the side of a steep hill or declivity, so that the mouth *a*, is equally accessible for charging the kiln, as the fire-place *d*, for stoking and introducing the fuel. The shaft is round throughout; 6 feet in diameter at the top, and gradually expands to 10 feet at about one-third from the bottom. A sudden contraction of the diameter is there introduced, forming a sort of projection inwards of 1 foot in width, and the size of the kiln then diminishes until it acquires a diameter of about 6½ feet

at the bottom. The projection or ledge is carried in the form of a ring all round the interior of the furnace, but not at the same height from the ground, inclining, as will be seen in the drawing, towards the stoking hole. The charging is carried on upon a certain fixed plan. The lime-burner begins by constructing a pointed arch *c c*, upon the ledge, with the large pieces of limestone which are selected expressly for this purpose. He forms, in this manner, a kind of support or foundation, upon which the other limestones are thrown in, at random, from above, the largest first, and the smaller pieces afterwards, which are also piled up above the mouth of the kiln. When the charge has been thus arranged, a pile of wood is erected in the space below the arch and ignited. The regulation of the fire is by no means an unimportant point, as the possibility of completing the burning depends upon the length of time that the arch *c c*, which acts as a support, will endure. The stones, composing this arch, being unconnected by any cement, and unhewn, and only touching in a few places so as to leave a free ingress for the flames, a slight shock will often cause the downfall of the whole, and put a stop to the operation. The sudden and powerful action of the fire, by expanding the stones very rapidly, and driving out the moisture with such force as to rupture the stones, will often produce a sufficient shock to create a catastrophe of this kind. The art of burning lime, therefore, consists in bringing the mass of limestone as gradually as possible to a red heat. The first period is called *the smoking*, because the gases evolved from the fuel, being too much cooled, are imperfectly burnt, and pass off in the form of a thick smoke. The temperature generally increases in a kiln of this kind, during the first two-thirds of the time, until it attains a white heat, and diminishes again in the last third. The firing must, however, be kept up until the uppermost stones have been completely burnt. During the firing, the bulk of the stones is much diminished, and the heap above the mouth of the furnace sinks gradually down. In a kiln similar to that in the drawing, the firing lasts 3 times 24 hours, and requires 60 stacks of beech wood (about 600 cwts.) to burn 400 butts (=4000 C. feet Hessian) of lime. A considerable time elapses before the furnace is sufficiently cool for the removal of the stones, which is effected through the stoking hole *C*.

The evils of such a system of burning, which involves an enormous waste of fuel (the loss of time not being taken into consideration), are obvious. The furnace must be allowed to cool each time it is discharged, and the entire amount of heat, or, what is the same thing, the whole of the wood employed for raising the very extensive sides of the kiln to the temperature at which lime is burnt, must be sacrificed. It is also evident that, in such a system of burning, the lower half of the limestone must be thoroughly caustic, while the upper portions are still in the mild state. The upper part is at a very considerable distance from the fire, and removed from the direct action of the flames, is burnt, consequently, at a much greater cost of fuel than would otherwise be necessary. At the same time, the lower layers in the kiln are exposed to the consant danger of becoming over-burnt, which very much injures the quality of the lime.

No further proof is wanting to show that these evils are due to the bad arrangement of the kiln, and that they may be diminished, although not entirely removed, by constructing these lime-kilns upon a better principle. A great advantage is gained by constructing the kilns of brick-work in a more solid manner, giving the shaft more appropriate dimensions and shape, and building the kilns in situations less subject to be obstructed in working by moisture, &c.

Fig. 229.

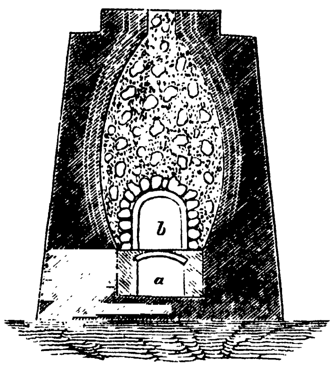
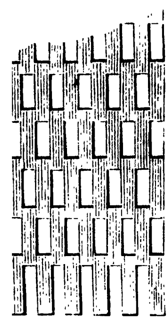


Fig. 230.



These improvements have been carried out in the kiln, shown in Fig. 229, employed in the neighborhood of Brunswick. Instead of a rudely constructed wall, an outer wall is erected in these furnaces with an internal one of solid brick-work. The fire is placed upon the grate which separates the ash-pit *a* from the fire place *b*. The grate is really a perforated brick arch, an upper view of which is given in Fig. 230.

The furnaces, constructed upon the plan of those in Rodheim, are only calculated for the consumption of wood, as a denser fuel, like coal or peat, would not obtain a sufficient supply of air upon the flat hearth to burn with advantage. In the case of peat, which leaves a voluminous ash, the draught is still more obstructed.

All kilns of the kind in question, or *intermittent* kilns, as they are called, are therefore furnished with a grate, when coal, lignite, or peat are used as fuel. The *perpetual*, or *draw-kilns*, are constructed upon the principle of avoiding all those evils from the commencement. The object is as apparent in the construction of the kilns as in the manner of working them. Fig. 231 represents a vertical section of a common form of perpetual kiln constructed for a coal-fire; Fig. 233 is a horizontal section of the same through the drawing-holes. The actual burning-space is a shaft in the form of an inverted cone, wide at the top and narrow at the bottom. There is no separate hearth; the apertures *a*, *a*, *a*, seen in front view at Fig. 232, of which there are three, serving only for drawing out the lime. A layer of brush-wood is first placed at the bottom of the kiln, upon this some coal, then a layer of limestone, which is again covered with coal and then

Fig. 231.

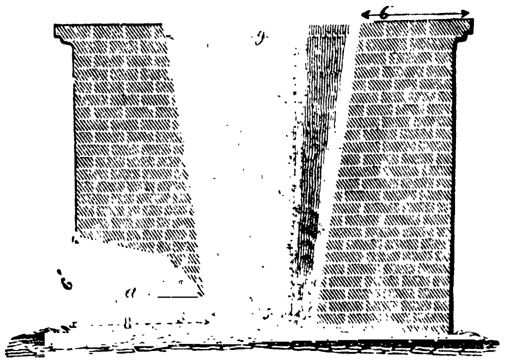


Fig. 232.

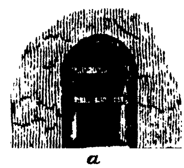
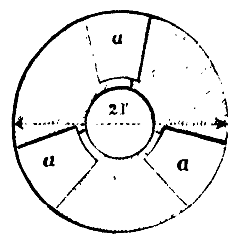


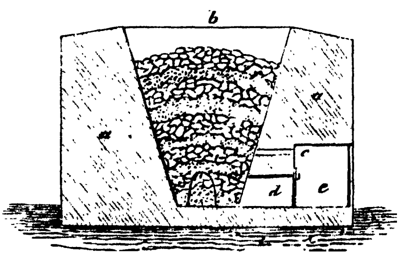
Fig. 233.



another layer of limestone, and so on until the kiln is filled. The last layer of stone is heaped up above the mouth of the kiln, and the progress of the firing is judged of by the manner in which it sinks down; the sinking in this case being due, not only to the diminution in bulk of the stones, but also to the consumption of the fuel. As soon as the uppermost layer has sunk down to the level of the top of the kiln, another charge of coal and limestone is thrown upon it. In the meantime, at intervals of $\frac{1}{2}$ to $\frac{1}{4}$ of an hour, the lime which has sunk to the bottom of the kiln is drawn out through the holes, *a*, *a*, *a*. The lower the charges sink in the kiln, the more the coal is consumed, and the less space they will occupy; for this reason the inverted conical form of the kiln is the most appropriate. The intensity of the fire can be regulated with perfect ease by adding more or less coal with each charge of limestone. The draught may be impeded by stopping the apertures, *a*, *a*, *a*, entirely or in part. In a kiln of the above dimensions, 500 cubic feet of lime are drawn in 24 hours, and the consumption of coal is about 2 tons.

Another example of the produce and cost is shown in a kiln of similar construction, (that of Luemschweller, near Mülhausen). The kiln is 14.4 feet high, 13.6 feet in diameter at the top, and 4 feet at the bottom; the grate being situated at a distance of 2 feet above the sole. It contains 400 cwts. of lime, of which $\frac{1}{3}$ is burnt in a day. The burnt stones are drawn, or allowed to fall down, by removing the grate-bars. A single layer requires 4 days to attain the grate, and consists of lumps of lime of about

Fig. 234.

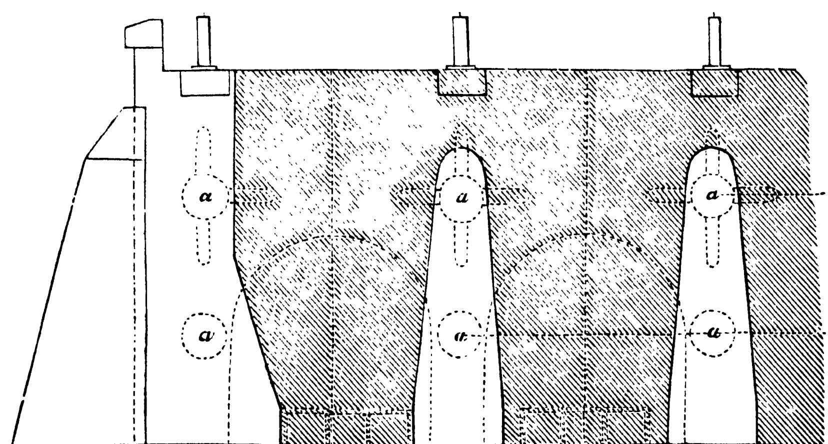


54 cubic inches as a mean. The consumption of coal amounts to about $\frac{1}{4}$th the weight of the limestone.

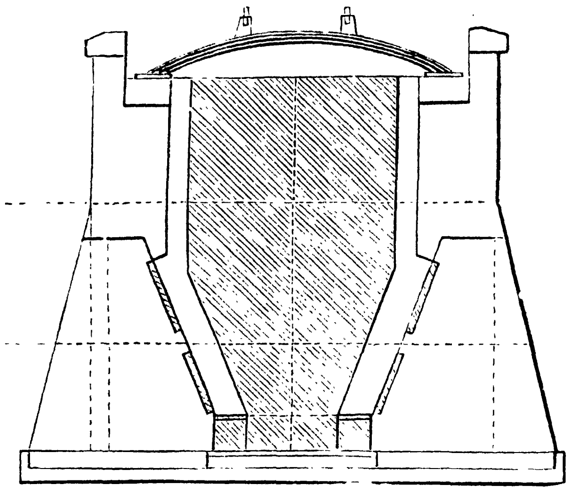
Fig. 234 represents a kiln with somewhat differently constructed discharging-holes, and shows the manner in which the coal and limestone are stratified in the kiln.

Coal is a kind of fuel that is easily broken in small pieces, or in the form of brees is already in a fit and convenient state for spreading about between the layers of limestone. Another advantage, arising from the use of coal, is the small quantity of ash which it leaves, and which is easily removed from the kiln with the burnt lime. These remarks do not apply to wood, which is reduced with difficulty into small pieces, and not being equally distributed amongst the limestone, impedes the regular burning and delivery of the lime; nor to peat, which in general leaves so large a proportion of ash as to subject the kiln to the danger of becoming stopped. In those cases, where a perpetual process must be combined with the use of wood and peat as fuel, the construction of the kiln must undergo a suitable modification. While the kiln retains its character as a perpendicular or shaft furnace, the fuel, instead of being interstratified with the limestone, is burnt on separate hearths at the sides of the shaft, and the flame is conducted into the latter, which, in this case, contains nothing but the material to be burnt. The number of the fires which must always be symmetrically arranged round the circumference of the shaft, is regulated by the size of the kiln, so that kilns with 3, 4 and 5 fires are met with. The fuel consumed in furnaces of this construction must, of course, yield a long and lively flame, as from wood, peat, or coal; but for the latter, the arrangement is not so economical as the plan of stratification previously described.

[Figs. 235 and 236 are sections of a range of lime-kilns, where



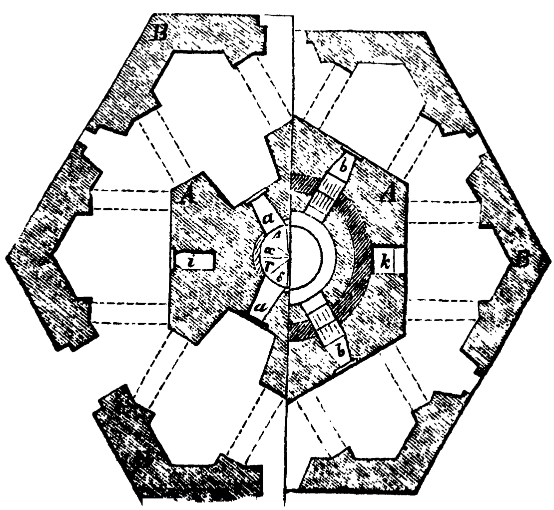
the amount of work to be done is very great. The shaded part is the body of the kiln, which is charged at once, direct from the wagons running along the top, on a railway. *a, a, a, a, a, a,* are iron clamps



for securing the masonry. The other parts of the drawings are intelligible without further description.

The best example of a lime-kiln, in which wood and peat are used as fuel, is that of Rüdersdorf, the only locality in the great plain that surrounds Berlin, where a deposit of limestone occurs, and which projects like an island from the surrounding tertiary formations. The

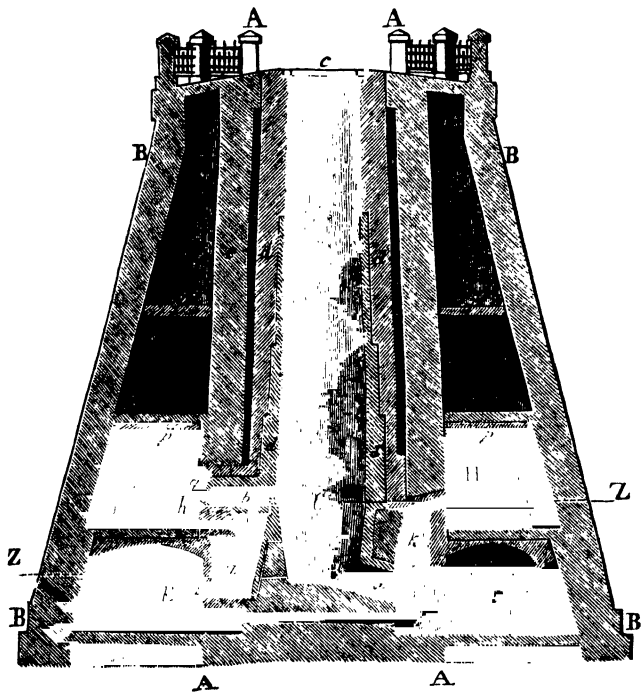
Fig. 237.



deposit belongs to the shell limestone (Muschelkalk) formation, and supplies the whole of the lime consumed in the capital.

The drawing, Fig. 238, shows a perpendicular section through the

Fig. 238.



middle of the shaft; Fig. 237, a horizontal section at the height of the fire-places, on the *right* hand, and at the height of the draught-holes, on the *left* hand of the dividing line, *Z*, *Z*.

The inner portion only, included between the letters *A*, *A*, belongs essentially to the kiln. The external wall *B*, *B*, *B*, encloses spaces under the arches *p*, *p*, *p*, the lower floors of which are used as magazines for keeping the fuel and lime dry, while the third and fourth serve as night quarters for the workmen.

The shaft is 47.7 feet (Hessian) high from the fire-place to the mouth, and from the sole to the fire-place is a distance of 8·8 feet, the whole is therefore 56½ feet high; the width of the kiln at the mouth is 7½ feet; at the sole it is the same, and at the widest part it is 10 feet in internal diameter. The whole extent exposed to the fire, 40.2 feet, is lined with fire-bricks *d'*, the lining being from ½ to 1½ bricks thick, at different heights, from the top downwards. This fire-proof facing is surrounded by the inner wall, *d*, *d*, which is unprotected above near the mouth. Both are surrounded by an outer wall, *e*, *e*, at the distance of some inches. The space between the walls is filled with ashes, and is called a *filling*. Its object is two-

fold: first, to allow of the expansion of the internal shaft, which is so considerable at the high temperature of the kiln as to burst a closely-fitting wall; secondly, to retain the heat, the ashes and air included in the intermediate space being very bad conductors of heat. On the three sides of the hexangular kiln, the fires, *b*, *b*, *b*, alternate with each other. The fuel is placed under an arch, *g*, which is lined like the shaft itself with fire-bricks, upon perforated slabs of clay, which conjointly form the grate; in the middle, where they come in contact with each other, they are supported by the girder, *f*. An iron door closes the entrance to the fire, by which means the fuel is kept better together. The draught has access to the grate through the channel, *h*. The ash collects in the pit, *i*; to remove it, the iron plate, *z*, is withdrawn, and the ash falls of itself into the space *E*, whence it is removed in barrows.

The apertures *a*, *a*, for drawing the lime, are widened towards the interior, in order to facilitate the descent of the lime, and that the arduous operation of removing it may be lightened as much as possible, the sole of the kiln is not only inclined towards the drawing-holes, but constructed specially so that the stones shall fall down of themselves. Towards the three sides, where the drawing-holes are situated, the sole is divided from the centre into ridges, so that the stones can easily slide down, upon their sharp edges, towards the drawing-holes. The draught through these holes would cool the kiln too much, as the fuel is supplied with sufficient air through the grates; they are, consequently, kept closed by iron doors, except during the time the lime is being withdrawn. In front of the drawing-holes, a perpendicular channel, *k*, passes upwards into the outer chamber, *H*; this is intended to protect the workmen from the intense heat, the hot air passing upwards into *H* before it reaches them.

While burnt lime is continually drawn from the bottom of this furnace, fuel is constantly supplied to the middle, and fresh limestone thrown into the mouth. The latter, which is brought into connection with the quarry by a railroad, is covered with a ring-shaped lid, *c*, and surrounded by a railing.

The first time the furnace is used and brought into work, the management of it is different. The work commences in a precisely similar manner as if no fire-places, *b*, *b*, were there, the shaft is filled up to that height, 8.8 feet, and the stones are burnt by a fire placed in the draught holes. When these are burnt, the shaft is completely filled, the stones being first let down in large casks, and afterwards thrown in until a heap is collected above the mouth, the fires are then ignited in the proper fire-places, and the ordinary routine of the kiln commences. Every 12 hours lime is drawn out of the kiln, from 60 to 72 cwts. (Hessian) at a time. The term perpetual kiln is not quite appropriate as applied to these kilns, the lime being drawn at intervals (of 12 hours in the Rüdersdorf kilns). Lime-kilns might be better divided, into such as must be cooled in order to withdraw the lime, and such as remain hot and work continuously.

There are at Rüdersdorf altogether two kilns with 3 fires, one

with 4 fires containing 2600 C. F., and one with 5 fires which holds 3000 C. F. of lime. The kiln with 5 fires yielded, in 12 hours, from 60 to 75 cwts. of burnt lime; it requires more fuel than the kiln with 4 fires, which yields the same amount of produce.

In the year 1829, for example, 26496 C. F. of limestone were converted into 19196 C. F. of burnt lime, which is equivalent to 72 per cent. of the volume; the consumption of fuel was 460 stacks of wood for igniting the kiln, and 547560 C. F. of peat for burning.

The limestone of Rüdersdorf yielded, in a special experiment, 52 per cent. by weight of burnt lime.

Consumption of Fuel.—Notwithstanding the great saving of fuel, which is effected in perpetual kilns, as must be obvious from the incontrovertible facts detailed above, yet it would be very inconsistent to judge all kilns by this measure, and condemn at once the simpler modifications first described. It must be borne in mind, that kilns, like those at Rüdersdorff, demand the entire attention of the workman, and cannot be well attended to as a casual occupation, or as a secondary branch of husbandry, for instance; it must also be remembered that perpetual furnaces are always yielding, that is, they produce, in the same time, a much larger amount of burnt lime, and are, consequently, only economical where there is a large and constant demand for the produce. An unqualified condemnation of the kilns first described, as employed in the Low Countries, would be absurd, there being no demand for large supplies in that quarter. Nevertheless, every improvement in their construction would be a great boon to the public, for they must be decidedly classed amongst the chief sources of the waste of fuel. The best mode of arriving at some sure foundation from which to calculate the amount of this waste, will no doubt be, by ascertaining the theoretical amount of fuel that is necessary to burn a given weight of lime, and making this result the standard by which to compare the real loss. At vol. i. page 79 it is stated that 1 lb. of wood fuel is capable of heating 26 lbs. of water 100° C. If the specific heat of limestone and carbonic acid is taken at $\frac{1}{3}$ that of water, and the temperature at which lime is rendered caustic is calculated at 800° C., it results, first, that 1 lb. of wood will heat $3 \times 26 = 78$ lbs. of lime to 100°, and consequently $\frac{78}{8} =$ 9.75 lbs. of limestone to 800°; or in other words and round numbers, only $\frac{1}{10}$ of the weight of the lime is requisite. In practice from 4 to 6 times as much is consumed. The limestone, it is true, does not lose its carbonic acid all at once, as the calculation presupposes, even when it has acquired the proper heat, but the acid is evolved very gradually; it is, consequently, not only necessary to heat the kiln for a single instant to the proper temperature, but to keep up that temperature for a considerable time. But, even if the quantity of wood calculated as necessary be doubled, on account of this latter circumstance, yet there still remains a loss of an equal quantity, and it may be positively asserted, that the quantity of wood consumed in the lime-kilns is about as much again as it should be. The heating power of coal being to that of wood as 60 : 26, for every 10 lbs. of

lime burnt there should be 0.43 lbs. of coal consumed. But, as was stated above, for every cubic foot of lime, from $\frac{1}{4}$ to $\frac{1}{3}$ cubic foot of coal is burnt, which is equivalent to from 2.4 to 3 lbs. of coal for 10 lbs. of lime, and consequently a very much greater waste.*

Lime may be burnt, like bricks, in mounds; but the irregular form of the pieces, and the contraction which ensues, render the process difficult, and it is consequently seldom practiced.

Produce.—Chemically, pure carbonate of lime loses 44 per cent. of carbonic acid, and yields, after burning, 56 per cent. of caustic lime (CaO). The produce from the kilns upon a large scale is much less when the limestone is very moist, and greater when it contains a large proportion of clay which loses nothing in the kiln. The average amount of produce obtained, ranges between 45 and 77 per cent., the ordinary quantity being about 54 per cent. The contraction is not so considerable as might be expected, as the burnt lime is very porous. The specific gravity of limestone is diminished from $\frac{1}{3}$ to $\frac{1}{2}$ by burning, and its volume is reduced from 10 to 20 per cent. Triest found, by direct experiment, the weight of a solid cubic foot (Hessian) of Rüdersdorf limestone = 93 lbs., after burning = 48 lbs.; the loss was, therefore, = 45 lbs. or 48 per cent. 100 lbs. of fresh Rodheim limestone, to give another example, occupy a space = 209, after burning (when they only weigh 60 lbs.), the space which they occupy is reduced to 183; the contraction, therefore, amounts to $12\frac{1}{2}$ per cent.

Besides the lumps or shells of lime, there is always a portion leaves the kiln in the state of powder, which is in consequence of the stones splitting in the fire, or is due to the friction in charging and discharging the kiln.

Action of Aqueous Vapor in the kiln.—Moist limestone is said by old lime-burners to burn much more easily than dry limestone. This fact, which is so well established among them that they prefer burning stones fresh from the pit, or even moisten those which have become dry in the air with water before putting them into the kiln, is

* In the calculations of the text the computed quantity of fuel theoretically supposed to be necessary for burning lime is based solely on the assumed *specific heat* of limestone and carbonic acid, and no account appears to be taken of the heat which becomes latent when carbonic acid passes from the solid to the gaseous state. This omission to consider the heat of elasticity is about as reasonable in the case of carbonic acid as would be a neglect to compute the latent heat of steam, and only taking account of the sensible heat imparted to the water in raising its temperature to the boiling point. In the case of *solid water*, or ice at the melting point, the heat of fluidity is 140 degrees and the sensible heat required to bring the liquid to the boiling point 180°. The sum of these two is 320 degrees only, while the latent heat of elasticity is 1030° (see vol. i. page 79), consequently the heat required both to melt the ice and raise the water to the boiling point is only about one-fourth of the whole quantity required to convert ice at 32° into steam at 212°. That the conversion of solid into gaseous carbonic acid is a process analogous to the conversion of ice or of water into steam is rendered evident, first by the fact that both operations require a continued high temperature, and secondly from what we know of the evaporation or *gasefying* of liquid carbonic acid, in which process, as seen in Thilorier's experiments, the heat becoming latent in the gasefied portion is so great as to convert a considerable portion of the liquid into solid or frozen carbonic acid with an intense degree of cold. Hence the waste of fuel is by no means so great as the computation of the text supposes.—AM. ED.

not without a true foundation, although it is often misunderstood in practice. In order to arrive at the true explanation of this phenomenon, we must remember the fact, that the same quantity of a gas or vapor ascends (although not so quickly) into a space already occupied by another gas (provided the space be not filled with the same gas) just as it would into a vacuum; the different gases possessing so powerful a tendency to permeate each other, that in doing so, they will often overcome a considerable resistance. Water, for example, evaporates as readily into dry air as into a vacuum; but the further evaporation is impeded when the space above the water, or the air, is already impregnated with aqueous vapor. The manner in which these phenomena affect the lime in the kiln has been demonstrated by Gay-Lussac in a very ingenious and satisfactory manner. Pieces of marble were placed in a tube, which was so arranged in a furnace that the temperature could be easily regulated. The one end of the tube was connected with an apparatus for the evolution of steam, and the opposite end with a contrivance for collecting the carbonic acid. The temperature was raised, so high at first, that the marble began to be rapidly decomposed, when, by impeding the draught, it was reduced to a dark red heat, so that all evolution of carbonic acid ceased. When aqueous vapor was permitted, at this moment, to pass over the red-hot lime, carbonic acid again made its appearance in considerable quantity, and continued to pass off under these circumstances in a manner entirely dependent upon the current of vapor. It stopped when the vapor was cut off, and began again immediately upon its admission. Hence, it follows directly, that the decomposition of the limestone is effected at a lower temperature by the agency of aqueous vapor than under ordinary circumstances. The same, however, may be effected by a current of air, as by steam, and the action of the vapor is, consequently, only mechanical, tending to form an atmosphere around the blocks of limestone, which is void of carbonic acid, and is thus in as fit a state for being permeated by the gas as a vacuum would be. In the one case, the escaping carbonic acid has to overcome the pressure of that which has already been evolved, while in the other, this is entirely obviated, the kiln being free from carbonic acid gas, or filled with a gas of a different nature.

That carbonate of lime remains undecomposed at a red heat in the presence of carbonic acid has been proved, as already stated, by Faraday and Hall. Petzholdt has even shown, that caustic lime, when exposed to a current of carbonic acid at a white heat, (at a temperature, therefore, at which the carbonate is speedily decomposed,) absorbs a sufficient quantity of the gas to effervesce vigorously with acids, and is no longer slaked in water.

When, on the one hand, therefore, it cannot be denied that limestone is more easily burnt under the influence of a current of steam, yet on the other, it is very questionable whether the practice of burning moist stones is really advantageous. The practice of bringing moist stones into the kiln is equivalent to the exposure of limestone very much below a red heat to the action of a current of vapor, as

far the greater part of the water must be uselessly expelled (with a proportionate waste of fuel) before the stones acquire a red heat. The small proportion of water retained in the interior of large lumps of limestone, when they have been brought to a red heat, is all that can be of actual benefit in the kiln. In perpetual kilns, the aqueous vapor expelled from the fresh charges (which carries away a certain portion of heat) might perhaps be conducted with benefit through the layers which are in the act of parting with carbonic acid. But the whole arrangement of the furnace must then be reversed; the fire-places of the kilns in Rüdersdorff, for instance, ought then to be placed at a short distance below the mouth, and the draught be conducted through a separate channel from above to the lower part of the kiln. The lower degree of temperature which can be used with the aid of aqueous vapor is, however, probably too inconsiderable to merit special attention. Experiments on a large scale, with a view to clear up this question, would nevertheless be well worthy a trial.*

The flame or the current of gas passing from the fuel, would of course only partially replace a current of air or aqueous vapor, as it contains a considerable amount of carbonic acid. Some furnaces, as that shown in Fig. 234, are specially furnished with a channel *c*, for conveying a current of air, with this view, through the kiln.

Burnt Lime.—To return from these remarks to the subject before us, it will not be unseasonable to examine the chemical changes which those limestones, that do not consist of pure carbonate of lime, undergo in the kiln. All the other carbonates lose their carbonic acid in the same manner as the lime; magnesia remains in the pure state, while the oxides of iron and manganese enter upon a higher state of oxidation. The water is simply evolved, and the bituminous and organic matters are burnt. An important mutual action is induced between the silica, both that in the free state, and that which is in combination with alumina and the lime. Lime, when burnt, combines with the free silica at a red heat, or enters as a constituent into the compound silicate of lime and alumina which is formed. It will be obvious from these facts, that the foreign substances must exercise considerable influence upon the quality of the burnt lime. In the purer varieties of limestone that contain but very little foreign matter, the influence is imperceptible. Berthier examined some specimens of lime, after burning, with a special view to ascertain the amount of this influence. As the clay and silica are less prominent in these instances, the action of the magnesia is rendered still more obvious, as will be seen in the following table, in which the other ingredients are not noticed:

* The improvements of Mr. Richard Tilghman of Philadelphia in decomposing various natural and artificial salts by the action of steam passing over them at high temperatures, are founded on principles analogous to those which govern the action of vapor on burning lime.—AM. ED.

Number	1	2	*	*	5	6	8	10
	The fresh stones contained:							
Carbonate of lime	97.0	98.0	96.5	95.0	94.0	87.2	74.5	60.9
" magnesia	2.0	0.0	2.0	1.3	1.6	10.0	23.0	30.3
	The burnt stones contained:							
Lime	96.4	97.2	95.4	93.5	91.6	86.0	78.0	60.0
Magnesia	1.8	0.0	1.8	1.0	1.5	9.0	20.0	26.2
Nature of the produce	very fat.	very fat.	very fat.	fat.	fat.	tolerably fat.	poor.	very poor.

Note.—All the other specimens, with the exception of the two marked with an asterisk, have already been noticed in the table at page 351, under the same numbers.

It will be evident from the above, how perceptibly the magnesia, when present to the amount of 10 per cent., affects the heating of the lime, and diminishes its property of slaking and forming a soft impalpable paste; in short, renders it poor. When the amount of magnesia exceeds ⅓, the poorness of the lime is so great as to render it useless. The nature of the limestones is not solely dependent upon the foreign substances which they contain, but also upon the mode of regulating the furnace; while one portion of the shells exhibits the proper amount of heat when slaked, other pieces will slake very slowly, and the water will often hardly act at all upon them; they are then said to be *dead-burnt*. There are several reasons which explain this: the stones have either not been sufficiently heated, and consequently still contain carbonic acid, or the heat has been of too short duration, and not intense enough in some parts, so that basic carbonate of lime ($2CaO,CO_2$) has been formed. The compound possesses the property of not slaking in water, but hardens and forms with it a compound consisting of carbonate and hydrate of lime (CaO,CO_2+CaO,HO). Fuchs has observed that the basic carbonate of lime, when fully burnt, the whole of the carbonic acid having been removed, sometimes, but not always, absorbs water very slowly and without any elevation of temperature; it acts, therefore, as if it were dead-burnt. The cause of this is unknown. A third cause of ordinary limestones being dead-burnt is, that the lime which enters into combination with the clay to form a compound silicate, cakes together on the outside of the large lumps, and forms an impervious coating which prevents the evolution of carbonic acid from the interior, so that an unburnt nucleus remains. This is what is generally understood by *dead-burnt*.

It is somewhat probable, that the above explanation will also apply to what has been observed with the oyster and muscle shells. These shells, although containing pure carbonate of lime, require a higher tempertaure in the kiln than ordinary limestone, and have a great tendency to produce a badly slaking lime. The gelatin in the shells is converted into charcoal which burns with difficulty, and is long retained

in the interior of the stones while the lime is burnt. Now if burnt lime is heated for some time intimately mixed with charcoal, the basic carbonate, mentioned above, is produced—according to Fuchs.

The phenomena in connection with this fact will be more closely investigated under hydraulic limestones.

The Slaking.—Burnt lime is of a whitish-gray color, or often dirty white, seldom pure white; it is much more friable than fresh limestone, but yet sufficiently solid to bear carriage. The crystaline structure of many varieties of lime is often distinguishable after burning. It is light and excessively porous. In consequence of its porosity, burnt lime absorbs water (about 18 per cent.) with the greatest avidity, during which operation the air contained in the pores is evolved with considerable noise. In a few minutes (but much later with poor lime) the saturated lime is observed to become hot, and from that moment the combination of lime and water proceeds. The lumps of lime fall to pieces with a crackling sound, and the smaller pieces are reduced to powder with the evolution of much steam, until at last the whole is converted, with a greatly increased volume, into a soft uniform white powder, *i. e.* into *hydrate of lime*. For building, it is customary to place the lime in *slaking tubs*, or into flat boxes constructed of boards, with a spout, and to pour as much water into them as will nearly cover the lime. During the slaking of the lime, the excess of water is heated to lively ebullition, and the workmen endeavor to mix the lime and water in a uniform manner with a rake. If the proportion of water was correctly estimated, a uniformly thick semi-liquid mass results. In the formation of hydrate of lime (CaO,HO), 100 parts of pure lime combine with 32 parts of water, or nearly $\frac{1}{3}$.

The conversion of liquid into solid water may be viewed as the proximate cause of the great evolution of heat which accompanies the slaking of lime, in as much as the water must be contained in this state in the solid hydrate of lime. Suppose 3 lbs. of lime to be slaked, these will combine with 1 lb. of water (at 0° C. (32° F.) for instance) and convert it into the solid form. In this process, a quantity of heat is liberated sufficient to bring 0.79 or $\frac{4}{5}$ lbs. of water to the boiling point. In practice the amount of heat is much greater, for a boiling temperature is attained when the lime is covered with three times the quantity of water. The conversion of water from the liquid to the solid state is, consequently, not the only source of the heat, the remainder must be accounted for by the chemical action which ensues. As a proof of this, the fact may be adduced, that lime heats with snow or ice. When a large excess of water is used, the heat evolved is more diffused and less intense; it increases with a lesser quantity, and attains a maximum when no more is added than enters into combination with the lime. The heat has then been observed to attain the temperature required to ignite sulphur and gunpowder, or even wood. If the lime is moistened with water in the dark, it becomes red hot and emits a lively luminous appearance; in this case, the heat is concentrated by the surrounding lime which is not in the act of being slaked. The heat is in general so much the

more intense the more rapidly the lime is slaked; or, is in proportion to its purity and the proper degree of causticity attained in the kiln. The temperature of slaking must always be attended to, as it influences the quality of the lime, and must be regulated by a cautious addition of water; when no more water is added to the lime than it can absorb, it does not form a soft, but a sandy (coarsely crystaline) powder, and is said to have been rendered *poor by slaking*. The builders have, therefore, a good reason for slaking the lime at once to the form of an impalpable, and not a coarse powder. Rather more than 3 parts of water are required for this purpose. In an experiment, 83½ lbs. of burnt Rüdersdorf lime, yielded, by slaking, 281 lbs. of a stiff paste, and had consequently taken up 197½ lbs. or 2.4 times their weight of water. Its volume was increased 3½ times, an amount which is sometimes diminished to 3⅕, and sometimes increased to 3⅗. This increase of volume, technically called the growth ("*Gedeihen*," "*Wachsen*"), depends quite as much upon the mode of slaking as upon the purity of the lime. If the lime, for instance, is only speedily dipped in water in a basket, so that it falls to powder, and is afterwards mixed with more water, it does not increase more than to 2½ volumes; if allowed to fall to powder, exposed to the air, and then made into a paste with water, it will only yield 1.7 volumes.

Influence of the Air.—Exposed to the air, burnt lime is converted very slowly, and without any elevation of temperature, into a rough coarse powder, containing small angular pieces; it then effervesces vigorously with acids. The lime under these circumstances is not completely converted into carbonate of lime, even after the lapse of three years, but, by the simultaneous absorption of carbonic acid and water, is resolved into the double compound mentioned above, which has been shown by Fuchs to consist of equal equivalents of carbonate and hydrate of lime, or (CaO,CO_2+CaO,HO). The formation of this salt proceeds very slowly, and the lime only ceases to absorb water and carbonic acid after the lapse of 3 months. When moisture is totally excluded from the lime, and dry lime is exposed to dry carbonic acid, none of the latter is absorbed after 8 days exposure. It appears, therefore, that the formation of carbonate of lime is a result of the decomposition of hydrate of lime, and that this continues until a certain point is attained, at which the attraction of lime for carbonic acid and for water is equal.

As large quantities of lime must be kept ready slaked for the purposes of the builder, and it is necessary to protect it from the action of the atmosphere which would render it useless as mortar, it is customary to preserve it in deep pits. The slaking tub is placed in front of a pit into which the slaked lime in the semi-liquid state is allowed to flow until the pit is filled. The lime becomes fatter and tougher in the pit, those pieces becoming gradually slaked which resisted the first action of the water. The excess of water collects on the surface and can be removed, the pit is then covered with a layer of sand 2 or 3 inches in thickness, and the lime is thus preserved totally unchanged. In removing the ruins of the castle of Landsberg

in order to lay the foundations for a new building, it is stated by Jahn, that a lime-pit of considerable dimensions was found in one of the vaults. The surface of this mass of lime was carbonated to the depth of a few inches, but all below that was in the state of freshly slaked lime, only somewhat more dry. This lime, which was certainly more than 300 years old, and valued at several hundred florins, was consequently used in constructing the new building.

It is well known that slaked lime dissolves in water, and 1 part of lime requires 778 parts of water at 15.6° C. (60° F.) for solution. The solubility diminishes with the increasing temperature of the water, so that the same quantity of lime is not soluble in less than 1280 parts of boiling water. Slaked lime in the state of paste is consequently a mixture of hydrate of lime with *lime water*, *i. e.* a solution of lime. Milk of lime contains so much of the latter that the whole is in the liquid state. Lime-water has a strong alkaline reaction; it has been observed, that when several portions of water are saturated from one and the same quantity of lime, that the first portion of lime-water has a much more strongly alkaline reaction than those which succeed it. Most limestones contain chloride of sodium and the silicate of an alkali. These salts are decomposed by the action of caustic lime; caustic potash and soda are produced, which absorb, (when coal has been used in burning,) partly sulphurous acid, and are converted into sulphates by exposure to the air, partly carbonic acid, and become carbonates of the alkalies. In contact with water and lime these latter are again converted into caustic alkali. This is of importance in many of the applications of lime.

Manufacture of pure Carbonate of Lime.—Quick-lime is heated with a solution of sal-ammoniac and the clear supernatant liquid decanted off. A current of carbonic acid, produced by the action of sulphuric acid on magnesian limestone, is passed through the previous liquid, and precipitated carbonate of lime is formed, while the sal-ammoniac is reproduced. The sulphates of lime and magnesia are employed for preparing pure Epsom salt, and gypsum, for the Venetian red pigment.

OF ORDINARY MORTAR.

Mortar is a mixture of *slaked lime* in the state of paste with *sand;* it possesses the property, when spread in thin layers between bricks, of gradually hardening to the consistence of limestone, and thus cementing the bricks together. In order to understand the principles upon which mortar is mixed, it is necessary to become acquainted with certain facts which here exert the greatest influence.

Conditions of hardening.—Simple lime, in the state of paste, likewise hardens, but only to form a loose mass of too slight consistency to bind the parts of a wall or building firmly together. It is only when the layer of lime forms a very thin stratum, as between two polished stones, that a firm and solid cement is produced. The lime

must be prevented from forming masses of any considerable thickness, as these always possess a very slight degree of cohesion. The lime attaches itself firmly only to the surface of the building stones, which differ from it in character, and this surface should be extended, as it were, by mixing a *granular powder* with the lime. This leads directly to the object and use of sand in the mortar, which is only intended to bring about more intimate contact between the surfaces of the stones and the lime. The shape of the bricks and hewn stones is so irregular, that crevices of a line at least, and in hewn stones often of an inch in width, are left between them when laid one upon another. Lime alone placed between the stones, would consequently be in layers of a line to an inch in thickness, and in such masses, would never bind. If, however, a sandy powder of any kind of stone is mixed with it, the mass of lime is thus divided into a great number of thin layers, or, as it were, fills up the interstices between the sand, and finding everywhere points of attachment, binds the grains of sand together, and extends this binding action to the stones themselves.

It is further known, that even the best mortar, when quickly dried, as for instance on the stove, does not harden, but remains friable and porous. Although, therefore, mortar placed under water remains porous and will not bind, yet the action of moisture is essential to make it harden in the air. Lastly, the free access of air is also absolutely necessary to the setting of mortar.

Proportions of Mixture.—When these facts are borne in mind, the rules to be observed in mixing mortar will be obvious. Although many kinds of stone in the form of coarse sand are applicable for making mortar, as limestone for instance, yet quartz-sand is always most easily obtained; the grain of the sand, however, is a matter of some importance. Very fine sand renders the mortar too dense, and impedes the free access of air; sand in grains, the size of a lentile, (particularly if it is angular or sharp,) is very appropriate; the interstices become too large to be entirely filled with lime, if very coarse sand is employed. It is then advantageous, particularly when irregularly shaped building stones are used, to mix two kinds of sand together, coarse and fine. Fine sand can only be mixed with the lime when the mortar is intended for a thin coating upon the surface of walls, &c. The more irregular the sand is the better. The proper proportion of sand and lime is a most important point in preparing mortar; and the good quality and solidity of the mortar are more influenced by it than by anything else. Errors committed in the mixing can never be subsequently corrected.

As a general rule, the lime should be sufficiently fine to cement all the grains of sand together, but should form at the same time the thinnest possible stratum between them. The surfaces of the grains of sand, or the interstices between them, should, therefore, be only just covered with the lime in a half liquid state, and no more. The rule might be laid down in the following terms: let as much lime be mixed with the sand as it will take up without having its volume in-

creased. Practically, about 3 to 4 cubic feet of sand (or 6 times the weight) are added to 1 cubic foot of half liquid lime, provided the lime be fat or very fat; poor lime, which may be viewed as already containing a certain portion of sand, will not bear the addition of more than 2½ cubic feet of sand to 1 cubic foot of lime. The sand should be pure, *i. e.*, it should not contain too much iron or clay and least of all, bog-earth, or particles of humus.

Hardening or Setting; time required.—Although mortar sets sufficiently in a few days, or weeks, to enable a wall to withstand pressure and the like, yet the hardening proceeds so slowly and gradually, that it only attains its maximum (in which case a wall appears as if constructed of one piece of stone), after years, or even centuries. The apparent superiority of mortar in olden times over that in the present, is solely attributable to the longer time which has been allowed it to harden and set, as no essential difference can be traced in the mixture of the ingredients. Although we see, on the one hand, that old buildings can only be destroyed with the aid of powder, and, as is the case at the Castle of Heidelberg, whole towers may be overthrown in a single piece; yet, it must not be forgotten on the other, that in some buildings the direct converse is observed, and that the durable portions only have been enabled to withstand the ravages of time, while the weaker and less durable parts have long since disappeared. In the same manner, it is probable that the buildings erected in our own age will stand forward to posterity as patterns of solid architecture, just as those of the middle ages and of the ages of Greece and Rome appear to us at present.

Cause of Setting.—The hardening of mortar upon exposure to the air is not so easily explained as would at first appear. It has even been disputed whether it is the result of mere physical (mechanical) or only of chemical agencies. There is no doubt, however, that both causes are concerned in producing the effect.

Absorption of Carbonic Acid.—The simple conversion of lime (CaO, HO) into carbonate of lime (CaO,CO_2) cannot be the chief reason of the setting of mortar; for, 1stly, the lime (as has been stated above) only absorbs the half of its equivalent of carbonic acid, becoming CaO,CO_2+CaO,HO; and, 2dly, it is well known that even in the most solid walls, the lime in the interior is still in the caustic state, *i. e.*, it contains no carbonic acid. On the occasion of building a new theatre in Dresden, a portion of the old fortified wall, which was upwards of 300 years old, was blasted, and Petzholdt took advantage of the opportunity for examining the mortar. A portion roughly pounded and digested in water yielded a liquid with a powerfully alkaline reaction (lime water). Caustic lime must, consequently, have been present. Cold muriatic acid decomposed the mortar with effervescence; after ten minutes the solution became converted into a stiff jelly, showing that a portion of the lime had been in combination with silica. Mortar taken from a house 100 years old, was acted on precisely in the same manner. The following are the results of the analyses of the mortars examined:

		300 years old.	100 years old.
Sand (insoluble in muriatic acid)	-	69.1	79.8
Silica (forming the jelly)	-	6.2	2.1
Alumina	-	0.4	0.016
Oxide of iron	-	1.4	0.16
Lime (CaO)	-	4.2	4.3
Water and carbonic acid	-	18.7	13.6
		100.0	99.976

In the first place, it will be seen from these specimens that the proportions of lime and sand are the same as those used at present, 4.2 of lime corresponding to 14 parts by weight of half-liquid lime; to which, in the older mortar, 69 of sand had been added, *i. e.*, five times its weight; and in the younger, 79.8 of sand, or 5½ times the weight of the lime. It is to be regretted that the amount of carbonic acid, in combination with the lime, was not ascertained, as we then should have been enabled to decide in what manner the hardening was influenced by the union of the lime with carbonic acid. But the analyses indicate clearly that another chemical force was engaged in aiding the hardening of the mortar. This is shown by the amount of gelatinous silica, or the presence of a silicate of lime in the mortar. Although a portion of this silica may have originally been in combination with alumina, as clay, and have been rendered soluble by being combined with lime in the process of burning, yet there is obviously a much larger portion present than would correspond with the alumina. Thus, the burnt lime of Maxen (whence the lime used in Dresden has always been obtained) contains only:

Sand	-	1.3
Silica (forming a jelly	-	2.6
Oxide of iron	-	2.1
Alumina	-	0.15
Lime	-	93.85
		100.00

so that there could be only 0.12 parts of soluble silica contained in the 4.2 parts of lime. We are, therefore, naturally led to the conclusion, that the extra quantity of soluble silica must have resulted from an action of the lime upon the sand, *i. e.*, from the formation of a silicate of lime in the humid way from these two sources, a process which would necessarily tend to aid the hardening of the mortar. The fact of 3 times as much soluble silica being found in the 300 years older mortar as in that which was only 100 years old, is also a corroboration of this opinion.

In order to arrive at a definite conclusion upon this point, Petzholdt instituted some direct experiments. 10 grammes of caustic lime, from Carrara marble, were mixed with 30 grammes of different sandy additions, and the mixtures were left to themselves, as if prepared for mortar. The mixture No. 1 contained, chemically, pure

silica that had been heated to redness; No. 2, quartz powder prepared from a piece of pure white rock crystal, which was quenched in water when red hot, and subsequently reduced to powder, and decanted from water; No. 3 contained white sand, as it is used in the kitchens for cleansing purposes; the coarser particles were first removed by a sieve, and the dust by suspension in water and decantation; No. 4 contained a brown, ferruginous, decanted sand; and No. 5 the same brown sand which had been previously purified by washing with muriatic acid. Of each number, 3 equal portions were submitted simultaneously to experiment, and observed at different periods. The results were as follows:

		No. 1	No. 2	No. 3	No. 4	No. 5
Soluble silica contained per cent.	in an 8 days trial	0.586	0.039	0.058	0.020	0.118
	in a 5 weeks trial	4.40	0.60	0.66	0.31	0.25

whence it is obvious, that the soluble silica is doubled, and even increased fifteen fold in the course of 5 weeks, and no doubt can any longer be entertained respecting the formation of a silicate of lime in the humid way during the setting of mortar. That the setting of lime is partly due to the formation of this chemical compound, appears, therefore, unquestionable; but that it is the chief cause, as Petzholdt supposes, is improbable, experience having shown, that any other kind of sand, not containing silica, can be employed with the same result as quartz sand. In the "*Pompejanischen Hause*" in Aschaffenburg, for instance, the stucco is a mortar composed of slaked lime and limestone sand. The mortar in the Roman baths at Gelnhausen contains "*Dolomitasche*" (a kind of limestone sand), in place of quartz sand.

There can be no doubt that the hardening of mortar must be attributed to other causes besides the chemical. Among these may be mentioned the crystalization of the hydrate of lime. It must be remembered that the moisture in fresh mortar is not simply water, but a solution of lime. In drying, therefore, when the water evaporates, the soluble lime will be deposited on the neighboring parts in very small crystals. These crystals are brittle, and break readily, when bent; but they are capable of resisting an action that tends to tear them asunder with very much greater force. If the surfaces, therefore, upon which these crystals have been deposited are closely approximated, a power tending to separate them will act upon the end of a very short lever, and endeavor to break the crystals in that direction in which they are able to offer the greatest resistance. Wherever the moisture in the mortar comes into contact with the air, on the outside, therefore, the carbonic acid in the atmosphere will precipitate the lime in small crystals which will resist separation upon the same principles as those stated above. The water will again dissolve lime, and this in its turn will become carbonated, which action will continue as long as moisture is present.

It appears probable, when everything is taken into consideration, that the hardening cannot be attributed to any one cause in particular, but to all collectively, and in such a manner that the formation of a silicate of lime, and crystalization, are the causes of the durable solidity and conversion into stone, while the absorption of carbonic acid induces the rapid setting of the mortar.

The Causes of Moisture and Efflorescence in hardened Mortar.—On the absorption of carbonic acid, an equivalent proportion of water separates from the hydrate of lime, which gives rise to the moisture on the walls of newly-built houses and rooms. The square fathom of inch thick mortar coating weighs above 3 cwt., and contains 13 lbs. of lime (CaO), with which from 4 to 5 lbs. of water are combined. In a room with a plastered surface of 10 fathoms, this will amount to 40 and some odd pounds. Some years ago, a plan for obtaining soda from lime and common salt was adopted by Guyton and Carny, in which the two substances were mixed and allowed to lie together for a time, until an efflorescence of carbonate of soda was visible. This process, although tedious and not calculated for the economic production of soda, shows clearly that the mortar must not be made with water containing common salt, and, least of all, with sea-water, as not only carbonate of soda, but chloride of calcium would then be formed, and this deliquescent salt would render the walls damp and porous. On a former occasion, (vol. i. p. 325,) it has been mentioned that, when nitrogenous matters (urine, &c.) are allowed to decompose in contact with walls, the presence of lime in the mortar gives rise to the formation of a species of saltpetre. The nitrate of lime is seen, under these circumstances, as a crystaline efflorescence on the walls. It would, however, be a great error to suppose that every efflorescence on walls was due to the same cause. In walls still in the act of building, where nothing of this kind could possibly occur, a white, mealy, often crystaline efflorescence is sometimes observed in spring-time along the layers of mortar; Vogel has examined some of these which were collected by Klenze, on the Glyptothek, and other new buildings in Munich. Kuhlmann has also paid more minute attention to this subject in Flanders, and elicited a series of interesting facts, which tend to confirm the results of Vogel's experiments. The efflorescences consist, according to the observations of both, of sulphate of soda, carbonate of soda, chloride of sodium, carbonate of potash, and chloride of potassium. They occur in walls constructed of sandstone as well as in brick-walls, and are consequently not derived from the stones, nor from the sand, (as has been proved by Kuhlmann,) nor from the fuel employed for burning the bricks, or the lime. The only source of these alkalies is rather the limestones themselves. It might be considered probable, that the alkali, from the ash of the fuel, was taken up by the limestones, but when burnt in close vessels, the latter exhibit, in the same manner, a certain amount of alkali, (page 372).

OF HYDRAULIC LIME.

Composition.—On quoting the analyses of ordinary lime, attention was directed to the fact, that those varieties which contain about 10 per cent. of silica or silicates, assume different properties, and although they are only slowly slaked after burning and poor, yet when made into a dough with water, they soon become solid, and exposed in this state to the constant action of water, acquire a high degree of consistence, and are rendered hard, like stone, without being subsequently loosened or eaten away by the water. These varieties are, consequently, an invaluable material for building under water, and are very appropriately called *hydraulic* (from ὕδωρ, water). As the hydraulic property is solely due to a chemical process, it can only be explained and understood by reference to the chemical nature of the stones. The following are the results of Berthier's analyses, with the exception of the last number, which was analyzed by Kersten:

The fresh limestones contain in 100 parts:

	1	2	3	4	5	6	7	8	9	10	11
Carb. of lime	90.0	80.9	89.0	89.0	85.8	82.5	80.0	79.2	76.5	83.4	79.10
" magnesia	5.0	3.2	2.0	2.0	0.4	4.1	1.5	2.5	3.0		
" protox. iron	—	—	—	—	6.2		—	6.0	3.0		
" protox. mang.	—	—	—	—	—		—	—	1.5	0.9	—
Silica	—	—	—	—	—		17.0	6.5	11.6	13.97	19.14
Alumina							1.0	3.8	3.6		
Oxide of iron	5.0	7.8	9.0	9.0	5.4	13.4	—	—	—	1.72	1.70
Carbon							—	2.0	—	—	—
Water	—		—	—		—	1.0	—	—	—	—

The lime obtained by burning the above contained in 100 parts:

	1	2	3	4	5	6	7	8	9	10	11
Lime	87.0	84.0	82.0	82.0	83.0	79.3	70.0	74.0	68.3		
Magnesia	4.0	2.5	1.5	1.5	—	3.5	1.0	2.0	2.0		
Clay	9.0	13.5	16.5	16.5	7.0	16.7	29.0	17.0	24.0		
Oxide of iron	—	—	—	—	10.0	—	—	7.0	5.7		

No. 1. Is a limestone from Vougy, in the Depart. de Loire; it is lamellar in structure, of a yellowish color, and is filled with ammonites and shells.

No. 2. Limestone from Chaunay, near Macon: it is of a yellowish-white color, dense and finely granular.

No. 3. Limestone from Digne (Jura); is solid, with knots of calcareous spar, containing graphite, and is of a dark gray color.

No. 4 Is a limestone occurring with the preceding variety; it is of a light gray color, but varies in appearance.

No. 5. Limestone from St. Germain; it is dense, of a dark gray, with white veins, or lamellar, with occasional masses of graphite. It is used universally at Lyons for building under water.

No. 6. Limestone from Nismes; it is of a yellowish-gray color, and very highly prized as hydraulic lime.

No. 7. Is a marly substance from Senonches (Depart. Eure et Loire);

it is disintegrated by water (not after burning). Silica remains undissolved when the stone is digested in muriatic acid; but this is completely soluble in caustic potash.

No. 8. Is a dense limestone, of unknown origin.

No. 9. Limestone from Metz; it is dense, exhibits an earthy fracture, and is of a bluish-gray color.

No. 10. Limestone-marl, from Blankenstein, and No. 11 is from Helbigsdorf, near Freiberg.

The first five numbers yield lime of very moderate, the last four, of a very marked hydraulic character. It will be seen by the table below, that this property increases with the quantity of matter insoluble in muriatic acid. This substance consists chiefly of a combination of silica and alumina, but is often composed nearly entirely of silica in the soluble modification. It becomes of great importance to obtain a knowledge of this insoluble portion, as upon it the hydraulic properties depend. This has consequently received more attention in recent analyses, as will be seen by the following examples:

Observer.	Hermann Meyer.					
Number.	1	2	3	4	5	6
Carbonate of lime	67.86	66.99	49.06	76.82	62.47	39.72
" magnesia	5.62	1.67	29.32	2.81	1.35	28·48
" protoxide of iron	3.30	6.95	16.83	3.21	5.85	7.50
Alumina	—	0.39	—	0.89	0.93	—
Total of the constituents soluble in hydrochloric acid	76.78	76.00	95.21	83.73	70.60	75.70
Silica	15.57	16.89	3.35	11.03	20.93	undetermined.
Alumina	4.18	4.32	0.86	2.86	7.72	
Oxide of iron	1.13	1.72	0.43	1.86		
Lime	0.15	0.005	0.06	0.12	0.12	
Magnesia	0.57	0.37	0.01	0.05	0.30	
Total constituents insoluble in hydrochloric acid	21.60	23.30	4.71	25.92	29.07	22.98

No. 1. Is the limestone from Krienberge, near Rüdersdorf (Berlin); it occurs below the sand. This variety belongs to the upper division of the shell-limestone (muschel-kalk); is in a state of great disintegration, and cannot be employed as ordinary mortar.

No. 2. Consists of limestone nodules, from the isle of Sheppy; it is yellowish-brown, massive and firm. These nodules are used in England for the manufacture of so-called *Roman-cement*, and occur in the London clay, which is a member of the tertiary formation.

No. 3. Limestone belonging to the shell-limestone formation, which covers the layer of lead ore at Tarnowitz. It is bluish gray, massive, and nearly crystaline.

No. 4. Cement-stone from the same locality, but fatter. In the manufacture of cement, these stones are mixed together in equal

proportions; they belong to the same subdivision of the Jura formation.

No. 5. Cement-stone, from Hausbergen, not very distant from Porta Westphalia, of a poor character; disintegrated, dark-bluish gray, slaty.

No. 6. The stone from which Koch's cement is made in Cassel; it is of a reddish-yellow, massive, dolomitic marl, from the lower shell-limestone.

Action of the Constituents upon each other.—In addition to the facts stated in the analyses above, it may be noticed, that the hydraulic limestones, as has been proved by Kuhlmann in the case of the Loudon and Boulogne cement, contain a larger mean quantity of alkali than ordinary limestones; a circumstance which has been overlooked by analysts, in the same manner as bromine, lithium and arsenic, were formerly overlooked in mineral waters. It will be further observed, that the hydraulic limestones may be separated, by the ordinary method of analysis, into two distinct constituents; the one consisting of carbonates of the earths, which, like the ordinary limestones, yield a fat lime; and the other, a silicate, or a mixture of silicates of alumina, lime, magnesia, and frequently of potash, with a greater or lesser excess of silica, which is consequently a kind of clay. In fewer instances, this ingredient, which many writers call siliceous clay, is composed almost entirely of silica. Thus the limestones from Klingenhof, near Strassbessenbach, in Spessart, (a variety of milk-white, very hard dolomite, from the mica slate, which is used in the potteries at Damm, near Aschaffenburgh,) consists of lime, with 19 per cent. magnesia, 40 per cent. silica, and mere traces of alumina. In burning hydraulic limestones, these two constituents, when the lime has once parted with its carbonic acid, will react upon each other, as a powerful base acts upon a silicate. The lime enters partially into the constitution of the silicate, producing a less stable compound than the original, which is easily attacked by acids. The amount of base in the aluminous silicate is, therefore, increased by burning, and greater facility is afforded for the action of acids. Burnt hydraulic lime is, in fact, (with few exceptions,) soluble in acids; and, in proof of the presence of a silicate that can be decomposed by acids, a thick jelly of silica is produced. This property of yielding gelatinous silica stands, therefore, in intimate connection with the property of becoming hard under water. Unburnt, pulverized stones do not harden, as is well known, and hydraulic lime, mixed with water, acquires a certain consistence much before it becomes hard. Moistened hydraulic lime produces, in the first instance, a connected, very soft friable mass, which is easily scratched by the nail; at a much later period, this mass, when covered with water, acquires a hardness which is quite equal to, and often exceeds that of, the limestone itself. As a general fact, the time in which different hydraulic limestones become hard is very variable, and the chemical action, which is the cause of the hardening, is consequently very unequal. The degree of hardness which they acquire is also not the same; those that harden slowly are

often more compact than those which harden in a shorter time. The time required for hardening varies from a few minutes to weeks and months, and bears some relation to the amount of the aluminous constituent in the lime. The more the limestones contain of this ingredient, the more quickly they harden. The hardening and solidification of the hydraulic stones being, therefore, dependent upon the chemical reaction of their two ingredients, the relative proportions of these cannot be a matter of indifference; and as there are varieties which, from the smaller quantity of the siliceous constituents contained in them, approach the ordinary limestones in properties, so there are others, in which this ingredient obtains so great a preponderance, and in which the amount of carbonate of lime is so small, that they no longer exhibit the hydraulic property. All mineral substances which possess the property of rendering ordinary limestone hydraulic, are very appropriately called "*cements*."* During the period of hardening, a very considerable rise of temperature is often perceptible, and the water employed is, in many cases, converted into a ley, which contains a quantity of alkali sufficient to produce the well-known slippery feeling between the fingers. This is the case with the hydraulic lime of Cassel. The alkali must necessarily be contained in the limestones, and must have been overlooked in the above analysis. The French engineer, Vicat,† who has made the study of hydraulic cements the object of his life, has divided them into classes, which are shown in the following table by as many examples that will serve as types:

Contains siliceous clay.	Moderately good hydraulic lime.	Ordinary hydraulic lime.	Best hydraulic lime.	Intermediate lime.	Bad intermediate cement.	Ordinary cement.	Best intermediate cement.	Transition to Puzzolana.
Before burning (to 100 carbonate of lime)	12	20	25	30	37	56	156	510
After burning (to 100 caustic lime)	22	36	44	53	65	100	273	900

* In technical language, hydraulic limestones, in which the properties are very strongly developed, are also called cements; thus we have *Cassel* and *London* cement. The great confusion of ideas connected with the term *cement*, has already been noticed in a former page, and care must be taken not to confound *hydraulic cement* with substances which are employed in the potteries, in the steel works, and in metallurgy in general, and to which the same name is applied.

† Although M. Vicat has acquired great reputation in France, and can boast the first scientific names amongst the heralds of his fame, yet that which he has accomplished does not come up to what we have been led to expect. Practice has, no doubt, to thank him for several valuable observations, yet his total ignorance of foreign literature has led him to publish much unnecessary matter, and his inability of penetrating beyond the surface, to the real scientific causes of phenomena, leaves him always in the middle between theory and empiricism, so that his compendious treatises can only be understood by few besides himself. A few only of his labors will consequently be referred to in the sequel.

This division is of course quite arbitrary, no classes existing in nature, but only transitions; it is, however, convenient when its true signification is borne in mind. There must necessarily be numerous exceptions, for this reason, that the property of hardening in one and the same specimen of lime varies with the temperature at which it has been burnt; thus several varieties belonging to the third class, when imperfectly burnt (*i. e.*, when the whole of their carbonic acid has not been expelled), yield a hydraulic lime of the second best quality. Vicat has determined in single cases the amount of imperfect calcination, by the amount of carbonic acid not expelled from the lime, and has tested the property of hardening in these different gradations. Thus one variety of limestone in which the carbonic acid remaining in it

Amounted to	30 per cent.	27 per cent.	26 per cent.	23 per cent	20 per cent.	10 per cent.
Yielded a mortar which hardened in	15 minutes	12 minutes	7 minutes	9 days	30 days	9 days

whence it is obvious, that, in the course of calcination, and with the increase in the amount of caustic lime, a great diversity of relations between it and the aluminous constituent are created, upon one of which, or upon several at once, the property of rapidly hardening is chiefly dependent. Too much heat in the kiln, and incipient fusion, render the lime very much weaker than it should be when the process is properly conducted, and at last disqualify it completely. It must be noticed, lastly, that hydraulic lime never hardens, when it is immediately immersed in water, before having acquired a certain consistence. In this case, the particles never agglutinate properly together, but form a porous mass.

Many limestones, particularly those which form the boundary between the hydraulic limestones and the cements, possess the very objectionable property of containing portions which slake at a subsequent period, when the greater bulk has already solidified, and become hard. The mortar then falls to pieces, and is rendered perfectly useless. It would appear as if particles of lime were in this case so enveloped, as only to become penetrated by the water in the course of the process of hardening.

Calcination.—Hydraulic lime is burnt in a similar manner to ordinary limestone; a much less degree of heat, however, is required. In Cassel, perpetual kilns, similar to that shown in Fig. 234, are used; they are of smaller dimensions, the fire being situated on a grate at the side. The burnt stones are reduced to powder under stampers; the powder is passed through a sieve, and is then in a fit state for use.

Those varieties of hydraulic lime which slake easily, need not even be reduced to powder. A great error is, however, committed in exposing the hydraulic lime (particularly in the state of powder) for any

length of time, during carriage, or in warehouses, to the moisture in the atmosphere; the greater part of its good properties are thus gradually destroyed, and it afterwards hardens very slowly, or not at all. It need hardly be mentioned, that a larger stock of hydraulic lime should never be made than is intended for immediate consumption. With reference to this point, Vicat has shown, that hydraulic lime which has once attracted moisture, may be made to set, by renewed pulverization and mixture with water; but the action is much slower, and it is converted into an article of the worst quality.

Theory of Hardening, or Solidification.—In the preceding paragraph, we have described the properties of hydraulic lime as they present themselves to direct observation, and we have still to investigate the theoretical causes of the hardening of these substances, and inasmuch as the process is of a purely chemical nature, to establish its connection with known chemical laws. In addition to the facts furnished by Berthier, Kuhlmann, and Vicat, the admirable researches of Fuchs, in Munich, have rendered the most essential service in explaining this curious phenomenon. The observations and conclusions of the latter philosopher tend to prove that the chemical process concerned in the solidification of hydraulic lime is due to the presence and mutual action of the *silica* and *caustic lime* contained in it. The final result is derived from two operations. During *calcination*, the lime is rendered caustic by the evolution of carbonic acid, and this caustic lime then reacts upon the siliceous clay, converting it into a compound that is easily decomposed by acids. The excess of caustic lime, as well as the compound into which the siliceous clay has been converted, then react upon each other, when mortar is prepared from the ground burnt lime, in such a manner, that a *solid stone-like silicate* is produced in the *humid way*. The water here obviously has a double action. Dry substances, like lime and the silicate of alumina, act very little, or, under certain circumstances, not at all, upon each other, unless the solvent power of water is employed to bring them into intimate contact. During solidification, the water will constantly transfer the lime which it has dissolved, to the siliceous particles; it will then dissolve fresh lime, which is again employed in the production of the silicate, and so on. The imperative necessity of keeping the hydraulic mortar in the moist state, after it has been employed in building, is thus explained. The other action of the water is the part which it plays in entering as water of hydration into the silicate which is formed. It must not, however, be supposed, that the hardening (as is the case with gypsum) is the simple result of the combination of water of hydration with a compound silicate produced during burning. If that were the case, many silicates, which are chemically similarly constituted—for instance, many of the zeolites—would likewise harden under water, after having been deprived of their water of hydration by burning, which is quite contrary to all experience. The process of solidification is, on the contrary, not so much the conversion of a ready formed silicate into a hydrate, as the *formation of a hydrated silicate in one and the same operation.*

Action of the Silica.—The molecular constitution of the silica is a point of the highest importance in this process. It is well known that silica exists in two modifications which exhibit very different properties. In the dense crystaline state, as contained in quartz, rock crystal, &c., silica is very little prone to exert a chemical influence in the humid way, but it acquires this property by the action of agents like lime, which render it amorphous and capable of entering into other combinations; it is contained in this state in some minerals, as, for instance, in the opal. The natural opal yields by itself a very tolerable cement with lime, as is also the case with precipitated silica. The action of quartz sand upon lime, on the contrary, as was stated under ordinary lime, is very insignificant, but is rendered much more energetic, when the quartz has been previously heated to redness with about $\frac{1}{3}$ of lime. Silica precipitated by chemical means, or gelatinous silica, removes the lime from lime-water with ease, although this is by no means effected by ground quartz.

The action of the Clay.—The silica may be replaced, as is indeed the case in the greater number of hydraulic limestones, by different silicates. Amongst these, the clays are the most important.

The great diversity in the nature of the clays does not admit of the supposition that their action is always the same, but nevertheless they all yield a substance with lime which hardens well, and in some cases affords excellent mortar. All must be previously burnt, particularly potter's-clay. It has already been stated in the chapter on pottery, that simple burning renders clay much more soluble in acids. In some cases, it is necessary to calcine the clay with lime. The common ferruginous brick-earth hardly binds at all with lime when only slightly burnt, but when strongly heated to the point of incipient fusion, the oxide of iron enters into combination with the clay, and a very powerful solidification then ensues with lime.

Amongst the silicates which contain constituents, or possess properties, in common with those which occur in lime, the following are worthy of notice.

Action of Iron.—*Lievrite* (a mineral composed of silicate of lime and iron) is almost without effect, although it contains 52 per cent. of protoxide of iron; the iron consequently only exerts an indirect action, as in brick-earth. This is also shown in the case of iron slags; those slags which contain a large quantity of iron, but little silica (slags from the puddling furnaces), are not available, while those which contain a large amount of silica, and little iron (blast-furnace slag), form a very good material for hardening with lime. (Compare artificial cements.)

Prehnite (a combination of silicate of alumina with silicate of lime and water of hydration) exerts no action in its natural state; but is very energetic after having been burnt. Calcination renders it soluble in water, with the formation of gelatinous silica.

In the crude state, felspar almost completely resists the action of lime; in the melted state, less; and least of all after having been

burnt with lime, when it forms a solid mass with an additional quantity. Glass reacts in a precisely similar manner.

The zeolites which contain, besides silicate of alumina, a silicate of an alkali, or silicate of lime, or both, such as *Analcime* ($2Na,O3SiO_3 + 3Al_2O_3,SiO_3 + 6aq.$), *Natrolite* ($NaO,SiO_3 + Al_2O_3SiO_3 + 2aq$), *Stilbite* ($CaO,SiO_3 + Al_2O_3,3SiO_3 + 6aq.$), are all soluble in the natural state in acids, with the separation of gelatinous silica, and yield even when unburnt, very good hydraulic mortar with lime; they, however, always act more powerfully after calcination.

Action of Alumina.—That the *alumina* in these minerals and in the clays is not the active agent, is proved by the case of cyanite, which has no effect upon lime, and which contains 54 per cent. of alumina in combination with silica, and is not decomposed by acids in the crude or calcined state. On the other hand, although the silica in the silicates is the essentially active principle, yet it is not so applicable in every proportion. *Pitch-stone*, which contains $\frac{3}{4}$ths of its weight of silica, *Pumice-stone*, which contains an equal amount, and *Obsidian*, which contains $\frac{4}{5}$ths, are not so energetic as opal.

Action of Magnesia.—Again, the silicates which contain a large proportion of *magnesia*, as *Steatite* ($6MgO,5SiO_3 + 4aq.$), *Tremolite* ($3MgO,CaO,3SiO_3$) and *Diopsite* ($3MgO,2SiO_3$), do not exhibit the least tendency to combine with lime under water; partly because they already contain an excess of base, and partly because the affinity of silicic acid for magnesia is greater than for lime. For the same reason, the tendency to solidify under water is very much augmented when magnesian lime is brought into contact with a siliceous mineral. The dolomitic limestones and dolomites afford, with proper additions, a much better hydraulic mortar than pure limestones; and their action is further increased, by the tendency which silicic acid manifests of combining in preference with two bases rather than with one. A very striking proof of the influence of the magnesia in the dolomitic limestones is afforded by the limestone from Tarnowitz, (No. 3 of the table at page 379), which hardens extremely well, although it only contains 3.3 per cent. of silica. This limestone contains 29 per cent. of magnesia. The two bases, lime and magnesia, according to Fuchs, are capable of combining and hardening under water without the addition or presence of any silica whatever. Dumas also states, that an artificial mixture of 36.8 parts of magnesia, with 44 parts of burnt lime (nearly equal equivalents, therefore, which would require 50 lime), when slaked and made into a paste with water, became tolerably hard after being left under water for 9 days. All the facts which have been adduced above tend to prove, that the reaction between the silica on the one hand, and the lime and magnesia on the other, is the chief cause of the solidification of hydraulic lime; but, as has also been stated, the degree of solidity is very much influenced by the molecular state of the silica and (when a silicate is employed) by the amount of base already in combination with it. The limit of saturation is indicated by Wollastonite ($3CaO, 2SiO_3$), which contains

48 per cent. of lime to 52 per cent. of silica, and which is without the slightest action, both in the unburnt and burnt state.

With reference to the part which is played by the alumina in the hardening, this is only a mediating and promoting action, for solidification occurs in cases where no alumina is present. On the other hand, Berthier found that mixtures of chalk with $\frac{1}{5}$th of alumina (calculated as anhydrous) are capable of being slaked, but do not become hard after the lapse of months. The frequent occurrence of alumina in hydraulic lime affords opportunities for the formation of double silicates with lime (together with magnesia, iron and alkali), into which the alkali exhibits a very marked tendency to enter, as is proved by the frequency of the natural silicates of this class.

Action of the Alkalies.—The alkalies also promote the formation of silicates in the humid way, although in a very different manner. When hydraulic lime, or a similar mixture, contains alkali, this will be entirely, or in great part, separated during the process of hardening, and dissolving in the water, will render it alkaline. Fuchs found that decomposed felspar, when treated in the humid way with caustic lime, parted with 10 per cent., that is, with the whole of its potash; he found, further, that a portion was liberated from pumice and pitchstone, both of which contain but very little alkali, and that both lithia and potash could be obtained in the same manner from lepidolite. By a similar process, the alkali is separated from most varieties of clay. The solubility of alumina and gelatinous silica in potash renders it more than probable that the alkalies accelerate the hydraulic action of lime by promoting and facilitating the gradual transference of the silica to the lime. An extensive series of experiments, undertaken by Kuhlmann, have at least proved that solutions of an alkaline silicate (soluble glass) part with their silica to lime without even the aid of heat. The same reaction occurs with carbonate and sulphate of lime as with caustic lime; the alkali combining with the carbonic and sulphuric acids, resigns its silica to the lime. Chalk powder, exposed for some time to a solution of silicate of potash, forms a mass which becomes, after some time, as hard as stone. Whole pieces of chalk, immersed in the liquid, become covered on the surface with a silicate of lime, which combination extends more deeply into the interior as the action is continued for a longer time. The surfaces thus prepared, harden when exposed to the air; and, without undergoing any other alteration, become so hard, that they are capable of taking a polish. Based upon these observations, Kuhlmann recommends the soluble alkaline silicates as a general silicifying medium for superficially hardening decorated walls by the production of this silicate of lime. Another observation of Kuhlmann's, that weak hydraulic lime (like that of Tournai) is rendered very much stronger by calcination with from 8 to 10 per cent. of potashes, is of more interest to the theory of the process than of practical importance, considering the high price of the potashes. In conclusion, it must not be overlooked, that the solidification of hydraulic lime is considerably accelerated by a high temperature and by increased pressure.

Action of Oxide of Manganese.—The views which were formerly promulgated respecting the cause of solidification of hydraulic lime, as, for instance, that of Guyton Morveau, who attributed the whole phenomenon to the presence of oxide of manganese, are totally untenable.

Artificial Hydraulic Lime.—A glance at the above theory, which is deduced from observation, is sufficient to lead to the conclusion, that artificial mixtures of appropriate silicates with lime, under proper treatment, must possess the hydraulic property in quite as eminent a degree as the natural productions. Experience has indeed anticipated theory in this fact, by several centuries. In very ancient monuments the solidity of the building is sometimes entirely dependent upon the weight and form of the stones employed. This is the case with the monuments of nations who existed prior to all historical record, and which, from their enormous size, are called *Cyclopian:* the Druidical remains, the Egyptian temples and the celebrated *Cloaca maxima*, built by Tarquinius Superbus as the common sewer of Rome, are all instances in question. The only mortar found in the ruins of Babylon, is bitumen or asphaltum. The Romans, however, were well acquainted with the use of lime mortar, and applied it both in the construction of buildings and roads; they also soon made the important discovery, that a certain soft, porous, almost earthy rock, containing pumice-stone, and resembling this in composition, and which was found on the coasts of the bay of Bayæ and Naples, particularly in the neighborhood of Puteoli, possessed the valuable property of forming an hydraulic mortar with burnt lime. They called the rock *pulvis Puteolanus;* it is described by Vitruvius and by Pliny, and was employed, mixed with an equal quantity of lime, for building under water. The *pulvis Puteolanus* was precisely the same substance as is known in the present day under the name of Puzzolana. The modern name of the town Puteoli is Puzzuoli.

Trass or Tarras.—After entering Germany, and having taken possession of the Rhine, the Romans soon recognized, in the layers of trass near Bonn, the well-known *pulvis Puteolanus*, and opened the quarries, whence this important material is distributed, far and wide, even to the present day. Both Puzzolana and trass are conglomerates of fragments of volcanic rocks, transposed by the agency of water from their original sites; they often contain fragments of basalt, pumice-stone, trachyte, clay-slate, &c., indicating at once the connection of the one with Vesuvius, and of the other with the volcanoes of the Eifel. The trass in Brohlthal is derived from the constituents of the trachyte rocks in the neighborhood; it forms very thick beds, often filling entire valleys, and is in the form of a friable, easily pulverized stone, the color of which is generally light, passing from a yellowish to a greenish hue. It is ground in a number of stamping-mills in the neighborhood, and exported in the form of a fine powder. Like most other volcanic productions, as basalt, klingstein, &c., trass is resolved into two distinct silicates by chemical agency. The one is readily soluble in muriatic acid, the other resists solution. Elsner obtained the following results from the analysis of these two substances:

Portion soluble in muriatic acid:		
Silica - - - - -	11.50	
Oxide of iron, with traces of manganese -	11.77	
Alumina - - - - -	17.70	
Lime - - - - -	3.16	
Magnesia - - - - -	2.15	
Potash - - - - -	0.29	
Soda - - - - -	2.44	
	——	49.01
Portion insoluble in muriatic acid:		
Silica - - - - -	37.44	
Oxide of iron - - - -	0.57	
Alumina - - - . - -	1.25	
Lime - - - - -	2.25	
Magnesia - - - - -	0.27	
Potash - - - - -	0.08	
Soda - - - - -	1.12	
	——	42.98
Water, with traces of ammonia - - -		7.65
		99.64

While the former constituent of the trass is essentially a silicate of alumina and iron, the latter is nearly pure silica, so that both contain the necessary conditions for a hydraulic material: silica (49 per cent. in all), to combine with the caustic lime which is added, 21 per cent. of alumina and oxide of iron, and, lastly, nearly 4 per cent. of alkali to assist in the manner indicated above, in retaining the silicates of all these bases in a disintegrated state: a condition which other substances, like clay, &c., only acquire by calcination with lime. As was to be anticipated from the analysis of a mass of fragments like those composing the trass, the results of different experimenters do not agree. As much as 57 per cent. of silica has been found, 28 per cent. of alumina, and 8 per cent. of alkali.

Puzzolana.—Berthier found the Italian Puzzolana composed of 44.5 per cent. silica, 15.0 alumina, 8.8 lime, 4.7 magnesia, 12.0 oxide of iron and titanium, 1.4 potash, 4.1 soda, and 9.2 water. It is consequently quite analogous to the Rhenish trass.

Another variety of Puzzolana, not of volcanic origin, has very recently been discovered by Sauvage in the Dep. des Ardennes. It there covers the clays of the gault, a fossiliferous formation below the chalk. It is of a pale gray or greenish color, very soft, and, according to Sauvage, is constituted in the following manner:

Soluble silica (gelatinous) - - - -	56
Clay - - - - - - -	7
Fine quartz-sand - - - - -	17
Fine gray limestone (chlorite) - - -	12
Water - - - - - -	8
	100

The very considerable quantity of silica is remarkable, and would lead one to expect a powerful hydraulic action, which, indeed, has been corroborated by Vicat.

Clay as Cement.—All those substances which render fat, slaked lime hydraulic, are called *cements*. Puzzolana, trass, and all similar cements have the advantage of requiring no preparation by burning, but are capable of acting in the natural state (of course in fine powder, that they may be properly mixed). A glance at the tables in pages 206, 207, and 210, shows at once that many clays approach the volcanic cements very closely in composition. But, in order to exhibit a like action, the constituents of the clays should also be in the same molecular state, which is, however, by no means the case. All varieties of clay, inasmuch as they are to be used for cements, must, therefore, be disintegrated by burning, with or without a certain proportion of lime according to their different characters. They then afford very powerful cements, which property, however, is very much influenced by the temperature to which they have been exposed, and the manner in which they have been burnt. Treussart made some bricks from a clay which is used in Strasburg for the manufacture of alum, and contains 50 silica, 32.7 alumina, 1.6 magnesia, with mere traces of oxide of iron; a part of these he burnt in the alum-furnace, and the others in a lime-kiln. When the burnt clays were made into mortar with half their weight of slaked lime, a great difference was observed in the two kinds; that which had been burnt in the alum-furnace, hardened in two or three days, and would withstand a weight of 400 lbs. without being crushed, while that from the lime-kiln did not harden for 30 days, and, placed in the same circumstances, broke under a weight of 50 or 60 lbs. A similar comparison, instituted with two mortars, also composed of 1 part slaked lime and 2 parts cement, the one of which consisted of simple clay, the other of clay that had been calcined with 2 per cent. of lime, led to the same result, in favor of the latter mortar, which hardened in 17 days, while the former required 30 days.

Several public buildings in France, and amongst others the St. Martin canal, are constructed with an artificial hydraulic lime from the manufactory of St. Leger, which contains a clay cement. This hydraulic lime is prepared by mixing 4 parts (by volume) of chalk from Meudon, with 1 part of clay from Passy, in the same manner as the body for earthenware is made. The two substances are first brought under an edge-stone mill with water, where they are ground to a thin slip, which is conducted into walled tanks and allowed to subside. When the water has been drawn off the surface, and the mud has acquired a certain consistence, bricks are moulded from it, which after being dried, are gently burnt in a lime-kiln. Berthier found in the unburnt mixture: carbonate of lime 84 per cent., silica 10, alumina 5, and oxide of iron 1 per cent. The whole quantity of lime is mixed in this case at once with the mass; one portion is employed to decompose the clay, and the remainder forms the hardening material, with the cement produced, which, when used, must be

slaked with water. It swells during this operation, when it has been properly burnt, the 0.65 of its volume.

Other substances as Cement.—Another more recent patent has been granted to Briaut and St. Leger, in which the cement specified is a silicate of lime, instead of clay. According to the published account, 4 parts of chalk (or any pure limestone) are mixed with 1 part of calcined silica, (quartz-flint, &c.,) ground to the finest possible powder, and the mixture is then burnt in the manner described above. As the presence of clay has in all cases been found advantageous, and clay is everywhere accessible and requires less labor in preparing than the siliceous minerals, the superiority of this latter process is not so obvious, and it cannot consequently be recommended.

When, however, limestone, free from iron, (chalk, &c.,) has been employed, a white colorless mass is obtained after hardening, which in some cases may be an important recommendation.

Instead of clay, other refuse of similar character and properties may be employed in the manufacture of cement, wherever it is to be obtained. Amongst these substances, the residue from the lixiviation of alum-shale and the ashes of coal, lignite and peat, deserve particular notice. It has already been stated above (page 154), that in the alum-shales, the argillaceous and carboniferous constituents are so intermingled, that when the shales have been roasted and lixiviated, in which latter operation alumina is removed, the argillaceous constituent has not only been rendered soluble in acids, but is also richer in silica than it was before, and is consequently left in a very favorable condition for yielding a good hydraulic mortar with lime. A glance at the observations and data given in vol. i. pages 28, 33, 39 and 49, will also show that the ashes of fossil fuel abound in silica, alumina and oxide of iron, and sometimes contain lime, magnesia and the alkalies. The ash passes through the bars of the grate at a red heat, and must consequently be in a condition to be very readily decomposed, and indeed it is capable of forming at once an excellent cement with lime. According to Anthon, the best proportions to be used are, 1 part of slaked lime to an equal, or up to a double quantity, of coal ashes.* The great differences in the ashes, from different varieties of coal, render it probable that these proportions will vary according to the source of the coal. The hardening of mortar, composed of lime and ashes, is, however, to be attributed partly to gypsum, of which some varieties of brown coal contain as much as $\frac{3}{4}$ths of their weight.

The excellent hydraulic mortar of Tournay, known under the name of "*cendrée*," is prepared from the refuse which is left on burning the lias limestone. This waste, which remains after removing the lumps of lime, consists of small fragments of lime and of the ash, (the coal there used yielding a large amount of ash,) in about the proportions of 1 : 3. The mixture is slaked in a small

* Pure ash is here intended, not cinders, which is a mixture of ash with a quantity of coke.

quantity of water, and before being used, is well beaten and worked about.

Dr. Elsner has published the following analyses of certain iron slags which are found to afford excellent hydraulic mortar when mixed with burnt lime:

	I.	II.
Silica - - - - -	40.12	40.44
Alumina - - - - -	15.37	15.38
Lime - - - - -	36.02	33.10
Protoxide of manganese -	5.80	4.40
Protoxide of iron - -	1.25	1.63
Potash - - - - -	2.25	2.07
Sulphur - - - - -	0.70	0.76

These slags in the state of fine powder, when treated with a small quantity of muriatic acid, are rapidly converted into a uniform gelatinous mass. The relation of the oxygen in the silica, alumina and lime is very nearly as $21.0 : 7.1 : 10.0 = 6 : 2 : 3 = 18 : 6 : 9$, whence may be deduced the formula : $3\big((CaO)_3,SiO_3\big) + 2(Al_2O_3,SiO_3) + SiO_3$ or $2\big((CaO)_3,SiO_3 + Al_2O_3,SiO_3\big) + (CaO_3,2SiO_3)$.

It is easy to ascertain whether a slag is suited for the production of hydraulic cement, by pouring over it, in the state of fine powder, a small quantity of hydrochloric acid; if it forms a gelatinous mass after a short time, it will then yield, with lime, a proper mixture for hydraulic mortar.

Copper slag, yielding 48 per cent. of silica by treatment with hydrochloric acid, was also found to possess the same properties.

Roman Cement.—It is a remarkable fact, in the history of hydraulic mortars, which originates, as we have seen, with the Puzzolana and Trass employed by the Romans, that the more the knowledge of their uses has been spread, the more substances have been discovered, which either act as hydraulic mortars themselves, or can be mixed as cements in the preparation of artificial mortar; so that what appeared originally a privilege accorded to a few favored spots only, can now be obtained almost everywhere. A strong inducement to study the nature and modes of occurrence of hydraulic lime, was created by the patent granted to Parker and Wyatt, in London, in the year 1796, for what they termed "*Roman cement.*" The material employed in the manufacture of this cement, are the nodules, of an ovoidal or globular form, which are found in the London clay, and known by the name of Septaria. They are not confined to the banks of the Thames, but are also found on the isles of Sheppey and Wight, as well as on the coasts of Kent, Yorkshire, and Somersetshire. The composition of these nodules has already been given under No. 2, of the table at page 378. They are calcined in perpetual lime-kilns with coal, in which a very moderate and well-regulated heat is carefully preserved. After calcination, the stones are ground under heavy edge-stones to a very fine powder, which is sifted and then packed in casks for sale.

In the year X of the French Republic, Lesage pointed out the existence of similar cement stones on the coast of France, near Boulogne, and Drapier proved their identity with the English, by chemical analysis.

Roman cement is one of the most powerful hydraulic mortars, and is exceedingly valuable, not only on account of the rapidity with which it hardens, and this is effected in a very few minutes, but because, when hardened in considerable masses, it is not liable to crack.

Since that time, similar calcareous marls have been found in numerous places, wherever pains have been taken to look for them, and have been used for similar purposes. To give an instance of this, Kittle, in Aschaffenburg, examined a series of limestones from the Spessart, and found in four different places in the neighborhood, limestone, which yielded a very tolerable mortar, and two varieties, which were excellent. Hydraulic lime has occasionally been met with in the same quarry as fat lime; and its nature not having been investigated, has been neglected as useless in consequence of the slowness with which it slaked.

All artificial or natural hydraulic limestones are soluble (before as well as after calcination) in muriatic acid with the separation of silica, except when sand or some similar substance has been added to them.

Practical Remarks.—The hydraulic limestones, when they do not contain a sufficient quantity of lime to be capable of slaking with water, must be very finely pulverized; it is only by this high state of division that a proper action can ensue. A thorough penetration of the siliceous portion by the lime is never entirely effected, but a certain proportion remains enclosed and removed from the sphere of action.

One point, which is very often neglected in preparing artificial hydraulic mortar, is the attention to the proper proportion between the slaked lime and cement. Both the ingredients must be mixed by measure or weight, and not merely estimated by the eye.

The best plan is to moisten the necessary quantity of cement first, and then mix the freshly slaked lime with it. The more uniformly and intimately both are mixed, the better is the result.

The hydraulic mortar employed in building the Eddystone lighthouse, was mixed by Smeaton from equal proportions of lime, slaked to powder, and Puzzolana. Trass and Puzzolana are generally mixed with $\frac{1}{2}$ their weight of lime, as was the practice amongst the Romans. It is desirable to ascertain the best proportions by experiment in all cases where no certain knowledge of the nature of the two substances can be obtained.

Good hydraulic mortar, whether made from natural limestone or composed of lime and cement, should not show any tendency to crack when hardened under water, even when no sand is mixed with it. It then forms a very dense and solid mass, which, in a short time, neither suffers water to permeate it, nor is attacked by the water, but

acquires a considerable degree of hardness. For this reason, it is well to use nothing but hydraulic mortar for those parts of walls which are constantly under water. If the mortar is not only required to harden, but also to bind well, a very important point must never be neglected, and that is to moisten the surfaces of the stones to which the mortar is to be applied. When this is not done, the surface of the stone (by its power of absorbing moisture), dries the mortar and prevents proper adhesion from taking place ; the joint then remains open to a greater or less extent.

It does not by any means follow, that because hydraulic mortar is the only durable material for building under water, it cannot consequently be used for dry walls. It is, on the contrary, of the greatest service wherever protection is required against the infiltration of moisture and damp ; and dwellings or buildings can often be rendered very much less damp by a judicious application of a hydraulic coating; a layer of this kind, when once hardened, is not calculated, like ordinary mortar, to attract moisture and allow it to pass through. The hydraulic mortar must, of course, when used for covering dry walls or otherwise, be kept moist and watered, until it has acquired its proper degree of hardness. If this is not attended to, a soft, friable, useless coating is the certain result. If moisture enters from below, for instance, between the wall and the coating of mortar, it will continue confined there in consequence of the impenetrability of the latter, which, on the occurrence of a frost, will most certainly peel off and be destroyed. Care must also be taken that the mortar does not dry up of itself immediately in the air, in which case, it contracts and cracks. It is, therefore, necessary to add sand or some other substance which obviates the shrinking. Hydraulic mortar will bear a very considerable quantity of sand without injury to its hardness, even as much as one and a half times its own weight and more. This addition, therefore, is important in an economical point of view. The grain of the sand employed, however, requires attention, as was the case with ordinary mortar ; sharp, angular sand is decidedly preferable to blunt rounded sand, and it is better to use a mixture of coarse with fine sand, than that the sand should be all of the same sized grain. The sand should likewise be as free as possible from earthy particles and dust. In mortar composed of lime and cement, the rule is, to proportion the sand to the quantity of cement used. Slaked lime will not bear more than a certain quantity of these substances, which quantity must not be exceeded, the cement itself being for the greater part inactive and playing the part of sand.

Hydraulic mortar that sets with sufficient rapidity, and to which a proper proportion of sand has been added, may be employed for casting tolerably massive objects, which are not subject to crack when dry. This enables hydraulic mortar to be employed for architectural ornaments which then combine great sharpness with durability, are very light as compared with similar figures of sandstone, and have the great advantage of being easily multiplied.

A similar application is that for casting water-pipes, on the spot

where they are required, as proposed by Gasparin. The mould employed is a linen hose, like those attached to the fire-engines, a few meters in length, which is filled with water and closed at both ends. A thick kind of bolster is thus produced, over which sand is sifted, and it is then laid upon a deposit of hydraulic lime and covered, by pouring over it the same substance. When the whole has hardened, the hose is drawn forward, about the length of one foot being left inserted in the tube, and a fresh length is cast. Water courses, thus constructed, must, however, have a certain amount of fall, or the sand cannot be washed out, and will impede the delivery of the water.

When hydraulic lime is mixed with small stones, or with shingles from the bed of a river, or the sea, walls can be directly constructed of it, and a mass is obtained which resembles the erections with ordinary mortar, and is called *béton* by the French.

At Toulon, a mixture was used for the construction of the harbor, consisting of 3 parts lime, 4 Puzzolana, 1 smithy ashes, 2 sand, and 4 parts of rolled stones or shingles.

The great strength of walls, constructed with hydraulic mortar, is most clearly shown by the experiments undertaken with a view to break beams constructed of brickwork. A 25 feet long, and 2⅓ feet wide beam, constructed with 19 layers of bricks, bound together by Roman cement, in which, here and there, parallel strips of iron were enclosed, was capable of bearing, when supported at both ends, a weight of 22 tons, suspended from the middle, before it showed signs of fracture.

[Careful experiments on the strength of various mortars composed of cement, lime and sand, have been made by various engineers, especially by Treussart, Petot and Courtois, a translation of whose several essays has been published by Lieut. Col. J. G. Totten, U. S. Engineer. He has also added experiments of his own, in illustration of certain points of the subject, some of the results of which are of such interest, as to deserve the attention of architects and engineers, as well as of scientific technologists.

Col. Totten used three kinds of hydraulic cement, two of which, "A." and "B.," were manufactured in New York, and the third was "Roman" or "Parker" cement, imported from England. He also used three kinds of lime, that of Smithfield, R. I., Thomastown, Maine, and Fort Adams, R. I. The lime was slaked in three different modes, viz: 1st, by sprinkling; 2d, by drowning, and 3d, by air-slaking. The "drowning" consisted in adding to the lime at once, water enough to reduce it to a cream, of such consistency as to afford mortar of proper temper, without the addition of more water.

The *sand* which he employed, was likewise varied in the size of its particles.

"*Sand No.* 1" was the kind habitually used at Fort Adams in stone masonry. It is entirely free from dirt; and when 100 parts by

bulk were sifted, the particles which were between $\frac{1}{5}$th and $\frac{1}{12}$th of an inch in diameter, were found to be 10.00 parts.

Those between $\frac{1}{12}$th and $\frac{1}{24}$th of an inch	- -	5.00 "
" between $\frac{1}{24}$th and $\frac{1}{48}$th of an inch	- -	48.00 "
" between $\frac{1}{48}$th and dust	- - - -	45.00 "
" true dust mostly silicious	- - - -	4.50 "

Showing the 100 parts now to occupy a space = 112.50 "

His *sand No.* 2, was the sand No. 1, freed from all particles larger than $\frac{1}{12}$th of an inch.

Sand No. 3, was the sand No. 1, freed from all particles larger than $\frac{1}{48}$th of an inch in diameter.

Sand No. 4, was sand No. 2, pounded very fine, after being freed from dust by washing.

Having tested both the tenacity and hardness of a great variety of mortars formed from these several materials, he deduced therefrom the following general conclusions:

1. Within the limits of the experiments, a mortar made of lime and sand, or of hydraulic cement and sand, or of hydraulic cement, lime and sand, (whether the cement was cement "A." or cement "B.," or Roman cement,) was the stronger, as the quantity of the sand was the less.

2. With cement A., or cement B., any addition of sand weakens the mortar.

3. When cement mortars are not required to be the strongest that can be made, a little lime may be added, without great loss of tenacity, and of course, with a saving of expense.

5. Mortar made in a mortar mill, is superior to that which is made by being mixed in the common mode, with the hoe.

5. When the bricks are dry and the mortar more fluid than usual, the mortar is better both as to tenacity and hardness, than when the bricks, being wet, are put together with mortar of common consistence.

Experiments were made to determine the effect of time in bringing the several mortars to a permanent state of tenacity and hardness, as effected by the mode of slaking, or the kind of lime. From these it appeared.

6. That whatever is the mode of slaking or kind of lime, the mortar is the stronger as the quantity of sand is less.

7. Lime slaked by drowning, or using a large quantity of water in the process of slaking, affords a weaker mortar than slaking by sprinkling.

8. The experiments with air-slaked lime were not numerous, but the results were unfavorable to that mode of slaking.

9. The mortars are very materially stronger at the end of 53 months, than at the end of 6 months; the increase of tenacity in the longer period was 57 per cent., and of hardness, 97 per cent.

10. Brick-dust or the dust of burnt clay, improves the quality of mortars both as to tenacity and hardness.

11. Hydraulic cement added, even in small quantities, to mortars, sensibly improves their quality.

12. The tenacity of mortar is increased after long exposure (53 months), by using it rather more fluid than usual on dry bricks, (as above stated for shorter periods,) but the hardness is rather greater when wet bricks are used.

13. In mortars of sand, cement and lime, the lime remaining the same in quantity, the mortars were stronger as the quantity of sand was less, in proportion to the cement.

14. In mortars of cement, sand, and lime—the quantities of cement and sand being the same—the mortars are stronger as the quantities of lime are less. This is not, however, universally true.

15. Mortars of cement and sand are materially stronger when the least possible quantity of water is used, than when the mortars are made thin.

16. Mortars made of cement and sand with the least possible quantity of water, are stronger when kept in a damp place, than when kept in a dry one.

17. In mixtures of lime and sand in various proportions, the mortar is generally stronger as the lime is slaked with less water.

18. Sand freed from dust by washing, and then pounded fine, gives much better mortars than a sand composed of particles of every size, from dust up to grains $\frac{1}{12}$th of an inch in diameter.

19. Mortars of cement and sand are injured by any addition of lime whatever.

20. Stone limes give better mortars than shell limes.

COMPOSITION AND STRENGTH OF CONCRETES.

Col. Totten also made several experiments to determine the relative value of various concretes. Having ascertained that the void spaces in sand No. 1 were 33 per cent. of its measured bulk, and that the filling of the void space with fine cement (in dust) would require at least that amount; and further, that to make the cement into stiff paste required 35 per cent. of its bulk of water, he inferred that to make 1000 parts by bulk of a mortar suitable for concretes, there would be required

of sand No. 1 - - - - - -	1000 parts
of cement - - - - - -	528 "
of water - - - - - - -	185 "

Experiments also proved that stone fragments nearly uniform in size and weighing about 4 ounces each, contain among them 68.0 per cent. of void space; consequently, to make a concrete of 1000 parts by measure of such fragments united by cement-mortar, composed as above, there would be required—

Stone fragments, about 4 ounces each -	1000 parts
Sand No. 1 - - - - - -	482 "
Cement in powder - - - - -	255 "
Water - - - - - - -	89 "

Besides the above described *granite fragments*, angular and of average weight of four ounces, other kinds of coarse materials were used to constitute the larger constituents of concrete, viz: angular *brick fragments* of four ounces weight; *stone gravel* made up of rounded pebbles from ½ to ¾ths of an inch in diameter, and *brick gravel* composed of angular fragments of bricks from ½ inch to 1 inch in their greatest dimensions.

The void spaces in the granite and brick fragments was 48 per cent., and in the stone and brick gravel 39 per cent. of the total measured bulk.

One set of experiments on these several coarse ingredients was made by using in each case a measure of mortar equal to the measure of void space, and another set, by using two such measures of mortar; the mortar in all cases being made with as small a quantity of water as possible. Prisms were formed in boxes by ramming the concretes forcibly into them, much after the ordinary manner of moulding bricks. Having been kept in a damp place for 6 or 8 months the prisms were broken by being placed upon two supports and weights gradually applied to the centre until fracture took place. It is unnecessary to cite the detail of the experiments.

The following general conclusions are, however, worthy of notice, as they serve to confirm the deductions in regard to mortars.

1. When the *mortar* with which the concrete was made, was constituted of cement, sand, and lime, or of cement and sand without lime, the concrete was the stronger as the sand was less in quantity.

2. A mortar of cement and sand is not improved by the addition of lime while the bulk of sand is only equal to, or is less than the bulk of cement; but as the quantity of sand is further increased, the mortar is more and more benefited by the addition of a small quantity of lime.

3. Two measures of mortar in concrete are better than one measure: that is to say, a quantity of mortar equal to the bulk of the void spaces does not give so strong a concrete as twice that quantity of mortar.

4. The best material to mix with mortar to form concrete, is quite small, angular fragments of brick; and the worst is small, rounded, stone gravel.

5. Grout, poured amongst stone or brick fragments, gives a concrete inferior, in general, to those obtained from mortars.

6. The strongest prisms of concrete after eight months' exposure was about half as strong as an equal prism of sound and strong red sandstone.]

Mr. Frederick Ransome has lately taken a patent for preparing different articles with a kind of vitrified cement. The following is the principle of his process.

Flints are suspended in wire baskets in a boiler of caustic alkali, which is heated to about 300° Fahr., under a pressure of 50 to 80 lbs. per square inch. A solution is thus obtained of silicate of soda or potash (of a sp. gr. of from about 1.3 to 1.6).

This is the cementing substance, the composition of which is said to be

Silica - - - -	20.43
Soda - - - -	27.05
Water - - - -	52.52*
	100.00

One part of this liquid cement is ground up with 1 part of pipe-clay, and 1 part of powdered flint, which are well mixed in a pug mill with 10 parts of sand or road-drift. The mixture is pressed into plaster moulds, and is then dried in the air on flat surfaces to prevent warping. It can now be handled, and is stove-dried previously to being placed in a potter's kiln, where it is heated slowly for 24 hours, and up to a fair red heat for 24 hours more, and then gradually cooled during five days.

This gradual annealing is essential, because the silicate of soda, during the firing, takes up more silica and alumina from the flint and clay, forming a true insoluble glass, which would crack if not properly annealed. The stone is not affected by boiling in nitric acid, which proves that an insoluble glass has been formed.

Sand and road-drift produce a white stone suitable for the face of ornaments, which are backed up with composition made of loam and silicate of soda.

According to the quantity of silicate of soda used, the stone may be either porous or impervious. If sufficient is used to fill up all the interstices between the grains of sand, the stone will be impervious. Some of Mr. Ransome's stone has been exposed for two years to the weather without the sharp edges being in the slightest degree injured; many porous stones will stand weather and frost better than impervious ones, and it is therefore still a question whether this stone will resist the action of air and rain loaded with sulphurous acid, as is the case in London. Some of the blocks of stone quarried at the island of Portland for St. Paul's Cathedral, and *left there*, are now quite perfect, whilst the stones in the Cathedral have become very much decayed.

Mr. Ransome in his patent, 22d October, 1844, merely directs the stone to be dried at 212° Fahr., or at a higher temperature, and does not say anything about *baking* it; he directs about ⅛th part of the silicate to be used in the mixture.† It was stated at the Institution of Civil Engineers, that slabs of 7 feet long, by 9 ins. × 3 ins., had been made perfectly flat and true, and that the reason they did not warp was, that the particles of sand were in contact with one another, and the cement only filled the interstices. If, on the contrary, too much cement were used, the shrinking of the cement would warp the slabs. Square blocks of this stone, we believe, may be procured for 3*s*. per cubic foot in favorable localities for the materials, fuel, &c., but the principal application for which it is intended, is for ornaments,

* Faraday, however, states the amount of water to be 75 per cent.

† See Chem. Gazette, vol. iii. p. 360.

as mouldings, rosettes, coats of arms, mullions, &c.; for elaborate forms may be given to it at very little more expense than is required for the simplest form. Terra cotta has been used for these purposes, but it warps in baking, and produces so many waste pieces, that it becomes more costly, and is less correct, than stone worked by hand in the usual manner.

Mr. Buckwell has also proposed a plan for making large masses, slabs, and pipes from stone and cement; but his invention does not apply to the manufacture of cubical blocks.

He uses fragments of stone as large as will go freely into the mould, mixed with other smaller fragments, of various sizes, to fill up the interstices as much as possible, the remaining space being occupied by the cement, composed of chalk and Thames or Medway mud burnt together.

One part of this cement is mixed with 8 or more parts of fragments of stone, and wetted with the smallest quantity of water, sufficient to moisten the whole; a portion of the mixture is then put into the mould to a depth of $1\frac{1}{2}$ inch, and rammed down by hammers or monkeys; another $1\frac{1}{2}$ inch is then added, and rammed down, and so on. The mould is perforated, and, although so little water has been used, it oozes out at all parts, showing that the effect of the ramming is to bring the particles of stone into much closer contact than could be done by any *simple pressure*. When taken out of the mould, the stone is hard enough to ring, and is fit for use in two days; it becomes still harder by exposure to air or water for some months.

New Portland stone fragments cannot be used for this conglomerate, because they crush into powder under the hammer; old Portland stone, which has become hardened by exposure, answers very well, and makes an artificial stone of greater specific gravity than Portland stone itself. The cement is harder than the Portland stone. Flaws, repaired by the mixture laid in with a trowel, are much softer than the cement in the body of the stone which has been consolidated by the ramming. The moulds are made of metal and are very expensive, which prevents the material being applied to ornamental purposes.

Separate pieces of stone can be joined by well ramming or caulking in the composition between them. For this purpose, of course, the pieces should be firmly fixed before beginning to caulk between them. Mr. Buckwell states, that he could execute entirely in his artificial stone the ordinary system of sewage, with improvements, at the *same* cost as the present mode of executing it in bricks. It may, therefore, be doubted whether it would be advisable to employ it. A new arrangement of sewage, which he proposes, would cost £2 10*s*. in his stone, for what would cost £15 in brick work: but it does not as yet appear why, in one case, artificial stone should cost as much, and in the other, only $\frac{1}{6}$th the price of brick.

An illustration of the effect of percussion in consolidating materials, may be taken from the fact that *concrete*, a mixture of gravel and lime, sets harder and better the greater the height from which it is allowed to drop into its place: in building the Royal Exchange, Lon-

don, it was shot in from a platform thirty feet above the foundation. It seems probable that concrete might be rendered still harder by mixing it with rather less water and ramming it well in its place. In Malta the roofs of the houses consist of flag stones placed in a nearly horizontal position; over the flag stones a bed of fragments of stone and a little clay is laid, which is moistened with water, and beaten and rammed until nearly dry: it is then covered with a layer of cement, formed of four parts of lime to three of puzzolana, moistened with water, and well beaten down until it begins to dry; this again is covered with a layer of dry stone fragments to prevent the sun from cracking it, which being swept off after a few days, a fine smooth impervious roof is obtained.

Hydraulic Fresco-painting.—In conclusion, we must notice a discovery of Fuchs and Schlotthauer, which was lately communicated to the Academy at Munich, and which has reference to a new mode of fresco-painting. While the fixing of the colors in the antique, as well as in the modern fresco-paintings, is due to the hardening property of caustic lime, when exposed to the atmosphere, the colored surface upon this new method is converted into a silicate of lime. The two older methods stand, therefore, in the same relation to the new one, as ordinary to hydraulic mortar. While fresco-paintings of the former kind are not very durable, (except in cases, as at Pompeii, where their preservation is due to the entire exclusion of light and air), and artists have reason to mourn over the destruction of the greatest master-pieces; those obtained upon the new principle are capable, not only of withstanding the action of water, weak acids and alkalies, but also the great changes of climate during a severe German winter, without injury to the freshness of the coloring; and the colors are so firmly attached to the ground that they exhibit no tendency to separate from it themselves, nor can they be removed by mechanical agency. The particulars of the process have not been made known, but it appears probable, that it is dependent upon the silicification of the lime mortar, by means of a solution of an alkaline silicate, of which we have previously spoken under soluble glass.

OF GYPSUM.

The gypsum known in the arts, is a combination of sulphate of lime with water; it contains 79·07 parts sulphate of lime, and 20·93 parts water, or one equiv. of the former to 2 equivs. of water (CaO, SO_3+2HO). The two equivalents of water are combined in a very different manner in gypsum, and play a very different part. While one equivalent is ordinary water of crystalization, the other may be viewed as saline water, or as water which can be replaced by a saline compound. This circumstance is the key to several peculiarities in the nature of gypsum.

Occurrence.—Gypsum is a mineral that never occurs in primitive rocks, but is found in all the subsequent formations in which water

has been concerned, beginning with the younger members of the transition rocks, to the fresh-water deposits of the tertiary formations. In the transition mountains it occurs so sparingly, that it is never obtained from them for technical purposes. The members of the secondary formations, on the contrary, and particularly the lias, the marls, the keuper, &c , and the shell limestone (*Muschel Kalk*), supply it in abundance. The masses of gypsum found in the tertiary beds are still more extensive. They are distinguished from the former, not alone by age, but by the organic remains, bones of animals, shells, &c., which they contain, and also by a certain proportion of carbonate of lime, in general, therefore, by a less degree of purity. The Paris Basin is the best instance of this kind of formation.

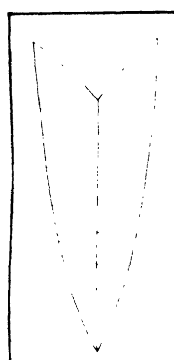
Gypsum is soluble in about 400 parts of water, and its solubility is not increased by a higher temperature. It is probable that the gypsum of the more recent formations has been gradually precipitated from water, while, in other cases, it may have been produced by the action of the vapors of sulphuric acid (for instance, from decomposing iron pyrites) upon carbonate of lime.

Gypsum does not often form connected layers of any great extent, like the clays and limestones, but occurs in remarkably isolated or detached, irregular deposits, not unfrequently subverting the neighboring rocks and penetrating into them.

In all the great varieties of form and character in which gypsum is found, a preponderating tendency to assume the crystaline form is always observed. Pure crystals of gypsum are very common, and are often of considerable size, sometimes in the form of lamellar twin-crystals, like swallows' tails.

A section of a crystal of this form is shown in Fig. 239, and similar crystals are frequently found attached to the bundles of twigs in the graduation houses, (see vol. i. p. 251,) where salt is evaporated by exposure to the air. Some crystals are so large that laminæ of several square feet may be cut from them, (called *Marien-glass* or *Craueneis,*) which are used as window-panes.

Fig. 239.



As a geological distinction, the varieties of gypsum may be classed under *granular gypsum*, a compact mass, composed of crystaline grains; the white translucent alabaster used in statuary belongs to this class, which, from its great softness, is capable of being cut with a knife and turned. Granular gypsum stands between *dense gypsum* on the one hand, in which the crystaline structure can no longer be seen with the naked eye, and *fibrous gypsum* on the other, which is frequently the substance that fills out fissures in rocks. The impure gypsum, containing carbonate of lime and clay, like that of Paris, is generally granular, passing into the dense variety.

Pure sulphate of lime, without water, so-called *Anhydrite*, is also a common natural production, and is generally found associated with

gypsum. Thus, for instance, anhydrite is found near Oldendorf as a nucleus, surrounded on all sides by hydrated gypsum. It is, however, of no technical importance.

Gypsum is used in sculpture, as alabaster; but its chief application is connected with its chemical nature, as a decomposing agent in different branches of manufacture, and as manure in agriculture: it is also largely employed as the material for plaster-moulds, and as a species of mortar. The ornaments composed of gypsum must be carefully preserved from moisture, as the substance is perceptibly soluble in water. Of the two other applications of gypsum, we shall have occasion to treat immediately; but with reference to the last, it is absolutely necessary to become acquainted with the mutual action of gypsum and water, in order to understand the theory of its technical application.

Properties of Gypsum.—Heated to 100° C. (212° F.) in vacuo, over sulphuric acid, gypsum parts with one-half of its water, that is, with its water of crystalization, and a combination of sulphate of lime with one equivalent of water remains (CaO,SO_3+HO). At a higher temperature the saline water is gradually expelled, and the gypsum becomes anhydrous below 150° C. (362° F.) Exposed to the free action of air, the process is somewhat modified; gypsum heated to 100° C. in the open air, loses scarcely any of its water; but this begins to be expelled at a slightly higher temperature, although it is not completely effected until the temperature has risen to 133° C. (272° F.) Gypsum, which has been deprived of its water at this temperature, attracts it again with the greatest avidity, when the two are brought into contact, and is again converted into the original compound ($CaO,2HO$). This recombination with water occurs in a few minutes, attended by an evolution of heat, when the proper proportions are observed. If the gypsum is in the state of powder before or after its water has been removed, and is brought into contact with water in this state, it sets or hardens very quickly, forming a porous earthy mass, which assumes the shape of the vessel in which it is contained. It is this property of gypsum which renders it valuable for casting figures and for mortar. It must be specially remarked, however, that when gypsum has been heated to a temperature between 133° C. (272° F.) (at which point it parts with its water), and its melting point, it loses the property of recombining with water altogether. It then acquires the properties of anhydrite or anhydrous gypsum, which does not harden with water any more than gypsum which has only parted with its water of crystalization, or the compound (CaO,SO_3+HO). It is probable that the difference in the properties of well-burnt gypsum and anhydrite is due to their different molecular arrangement.*

* [Besides the varieties of gypsum found in a natural state, and composed as above stated, there is an intermediate variety sometimes found in nature and often produced by art. A frequent exhibition of this material is made in the hard white crystaline scale, adhering to the interior of steam-boilers. According to an analysis of this scale, which will be found in the *Journal of the Franklin Institute*, third series, vol. xiv. p. 226,

The dehydration or calcination of the gypsum, and its subsequent mixture with water, are the two points, therefore, which require special attention.

Calcination of Gypsum for Stucco.—The finest and purest varieties of gypsum, for making casts and for stucco, are brought for the greater part into commerce as a fine powder in the unburnt state. Artists prefer burning it themselves, as the safest plan for securing the proper temperature, upon which very much depends, particularly as this does not require to be very high. The powdered gypsum only requires to be heated in a metallic vessel over a moderate fire. In a short time, a kind of motion is observed in the mass, it appears as if it were borne up and suspended by the aqueous vapor which is evolved, and presents a level surface, as if it were a liquid. Numerous craters then appear, from which the aqueous vapor is expelled, and which are renewed, after having been temporarily destroyed by stirring. By the movements, and the manner in which a glass or metal plate is bedewed when held over the vessel, the progress of the dehydration can be very accurately estimated, and the process stopped at that point when the gypsum has acquired the proper state of dryness. The *rapid solidification* of the gypsum, for all castings and purposes of the fine arts, is a most essential condition. Artists have found, by experience, that gypsum, entirely deprived of its water, does not harden so rapidly as that which has only been burnt or heated as long as the tumultuous expulsion of vapor lasts. In this case, the gypsum retains about $\frac{1}{4}$th of its water. The cause of this has never yet been explained, and it is the more extraordinary as gypsum which has retained the half of its water (CaO,SO_3+HO) has no tendency whatever to harden with water.

Instead of a vessel or pan, a hot metallic plate can be used to ensure the proper degree of burning, and it is only necessary to stir the mass well, that the heat may be uniformly disseminated. This cannot be done to such an extent in the baking-oven, in which gypsum is very frequently burnt. The gypsum is not generally pulverized for baking in the oven, but the picked stones are broken into pieces of the size of an egg or walnut, and spread out upon the sole. It is well known, that the ordinary ovens of this description have no separate fire-place, but only the sole, upon which a certain quantity of brush-wood is burnt. The baking is then effected simply by the heat

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we have shown that the specific gravity of this artificial gypsum is 2·695, that it is laminated, being formed in distinct layers upon the interior of the metal of the boiler; that it has a crystaline structure, minute prismatic columns crossing the successive layers and making a continuous mass, and that the planes of stratification are marked only by variations of color in the several successive deposits.

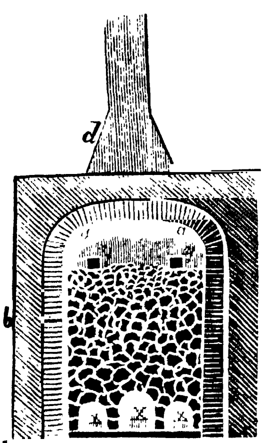
Upon a very careful analysis, this substance was found to be composed of two equivalents of dry sulphate of lime, to one equivalent of water ($2CaO,SO_3+HO$), or it was a *di-hydrated gypsum*. Natural minerals of the same composition are found in Nova Scotia, and in the salt region of south-western Virginia. The same composition had been found in some minute crystals detected among the sediment of a steam-boiler, by Professor Johnston, of Durham, England. A good solvent of this scale gypsum, is acetate of potash, yielding by double decomposition, acetate of lime and sulphate of potash, both soluble salts.—AM. ED.]

which has been absorbed and retained by the brick-work of the walls. The temperature required for baking gypsum, is very much the same as that required for baking bread, and is estimated by the hand being able to bear the heat of the oven for a few seconds. As soon as the sole of the oven is freed from the remains of the fuel, and the charge has been introduced, the door is closed. After a short time, pieces are taken out as trials. When these exhibit on the white, earthy, fractured surface only a few shining crystaline or still hydrated particles, the proper point has been attained, and the charge must be removed, in order to be ground and sifted. As the baked gypsum is much softer and more friable than that fresh from the quarry, this method is also advantageous on that account.

Mode of burning near Paris.—In those places where the process is carried on upon a larger scale, as at Paris,* where a very abundant bed of gypsum is worked for an extensive market, special plaster-kilns, or ovens, are employed for baking the gypsum. All these kilns, independent of a much less perfect regulation of the heat, give rise to an evil which can never occur in the other two plants. This consists in the gypsum coming into immediate contact with the fuel, or at least with the flame. It is well known, that charcoal (carbonic oxide and carburetted hydrogen) deprives gypsum of its oxygen at a red heat ($Ca,SO_3+4C=CaS+4CO$), so that sulphuret of calcium remains, which evolves sulphuretted hydrogen when exposed to air and mixed with water.

The most general arrangement, Fig. 240, is something between a meiler, or mound, and a kiln. The whole forms a quadrangle of 10 feet square and 9 feet in height, which is covered at the top with the arch, *a*, and is enclosed on two sides by the walls, *b*, *b*, and at the back by the wall, in which the chimney, *d*, is erected. The front is left entirely open, for the convenience of charging and regulating the fire. Beyond the surrounding walls, no arrangements are made, and the fire-grates in the interior are always constructed afresh from the materials to be burnt. The burners select the thickest gypsum blocks, and build up the arched channels, X, X, X, in a direction from the front of the kiln towards the flue. Above these channels, which represent the fire-places, the remainder of the larger lumps, then the middle sized pieces, the small pieces, and, at the highest part, the refuse and

g. 240.

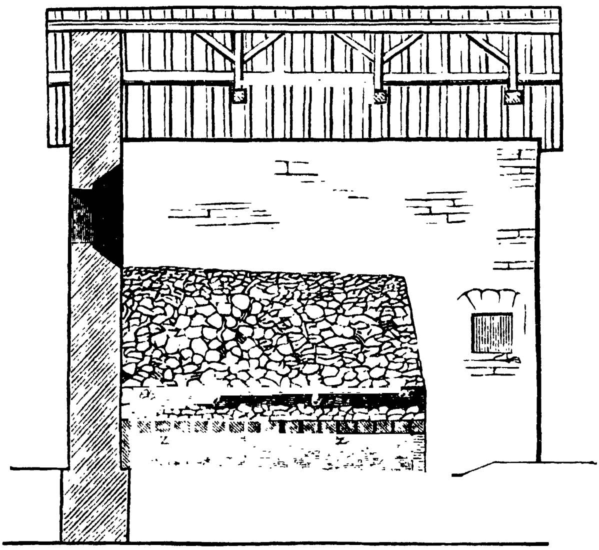


* In Paris, the workmen at the quarries sort the gypsum into three qualities; the worst forms granular amorphous masses, containing about 12 per cent. of carbonate of lime, which is used for mortar and as a manure; the second is the pure crystaline gypsum, lamellar, transparent, yellowish or colorless, occurring in groups or nests of various sizes, which is used for making casts; the third quality is alabaster.

powder are placed; a wood fire is then made in the channels, X, X, X. The flame escapes through the apertures in the wall, *y*, *y*, into the chimney.

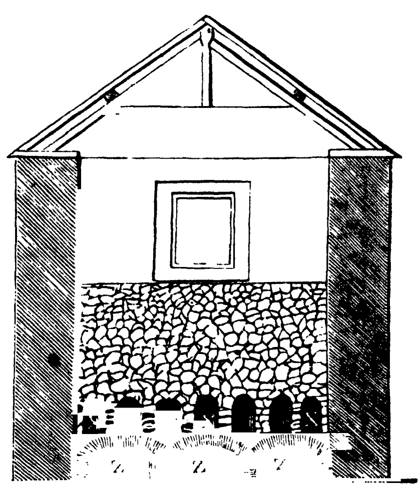
Burning with Coal.—When coal is used as fuel, the same arrangement of the stones is made in the kiln, but the ash of the coal must

Fig. 241.



be removed. Thus in Figs. 241 and 242, below the arches X there is another series of perforated bricked arches, Z. Upon the latter the coals *e*, *e*, are placed, while the ash falls through the perforated bottom. A special chimney is not used in these ovens. In from 12 to 16 hours, when the lower layers of gypsum have become red hot, the upper layers are sufficiently baked. The exposed nature of these kilns renders it very difficult, or nearly impossible to regulate the heat, and the temperature is always higher than is either necessary or desirable. The lower lumps of gypsum are always so much overheated that they

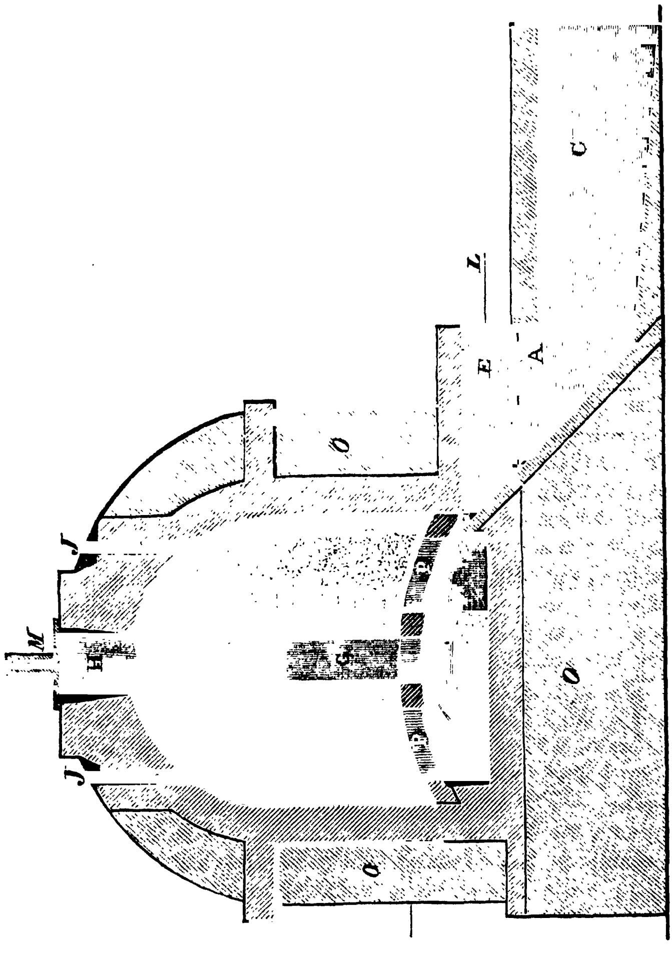
Fig. 242.



will no longer set with water; they are said to be *dead burnt*, while the upper layers are imperfectly dehydrated.

The furnace or kiln proposed by Scannegatty and shown in Fig. 243, is far better calculated for a proper process of calcination. The entire inner chamber is divided into two unequal parts by an arch *P*, *P*, situated about a foot from the bottom. The upper part, into which

Fig. 243.



the gypsum is introduced, partly through the door *G*, and partly at the mouth *H*, is provided with 8 draught-holes *J*, *J*, *J*; the ninth draught-hole is formed by the tube in the covering plate *M*. The lower chamber, or fire-space, is in connection with the fire *E*, which is situated in front of the kiln. The draught-channel *C*, terminates in the ash-pit under the grate *A*, on which a coal fire is made. The flame enters at *x*, below the perforated arch *P*, where it is uniformly

disseminated over the whole area of the kiln, in an upward direction through the gypsum, and makes its escape through the apertures *J*, *J*, *J*. If the heat is not uniform throughout the kiln, the registers *J*, *J*, are opened on that side where it is least intense and where it is desirable to lead the flame, while those on the other side are closed. The aperture *L*, is used for clearing the fire-chamber; this, as well as *G* and *H*, are closed during firing. As soon as the temperature has risen to the point when aqueous vapor begins to issue from the registers *J*, *J*, the object is to retain the kiln at that particular temperature, and trials are made at short intervals, in order to see whether aqueous vapor is still deposited upon a cold metallic plate, held over the apertures. When this dew diminishes, all the entrances to the kiln are closed, and the gypsum is allowed to cool during from 12 to 15 hours. The kiln has a capacity of 325° C. F., and will hold 220 cubic feet of gypsum, so that 100 cubic feet are occupied by the interstitial spaces.

The properties of the gypsum clearly point out the necessity for calcining it at a low temperature, which is confined between very narrow limits.

Evils attending the Calcination.—This condition, and the evils attending the free action of the flames, would render it inconceivable why, in practice, the old method has not long since been abandoned, where the process is carried on upon a large scale, and the calcination effected with steam heat or with hot air, which have often been proposed, if the simplicity and economy of the ordinary mode of treatment were not in themselves a sufficient explanation. The temperature of the steam might be easily regulated by attention to the pressure, while hot air would have the advantage of being forced directly through the gypsum, a plan which would be impracticable with steam. All the evils, over-and under-burning, dead-burning, and conversion into sulphuret of calcium, would thus at once be avoided.

In the kilns of older construction, the greatest evil consists in being obliged to place the gypsum in large lumps in the furnace, which are with difficulty burnt thoroughly to the centre. Every kiln is objectionable in which the gypsum blocks cannot be reduced to the size of an egg before calcining.

Grinding.—The grinding of gypsum is a very easy operation, in consequence of its soft, mellow nature. It is sometimes effected under stamping-mills, sometimes under edge stones, but most frequently in mills of the same construction as flour-mills. Rolling-mills have also been recommended. The pulverizing barrels shown in Fig. 144, vol. i., and described in vol. i. p. 361, are equally well adapted for this purpose. For making casts of medals, figures, and for stucco, a fine and uniform grain is essential, and for these purposes the gypsum must be in the most regular and uniform powder.

Preparation of casts.—The elevation of temperature, which always ensues when gypsum combines with water, is explained upon the same grounds as were stated at page 370, with reference to lime. Although gypsum only combines chemically with $\frac{1}{4}$th of its weight of

water, yet it possesses the property of solidifying and forming a firm connected mass, with an equal weight or even more, in short, with as much water as is necessary to convert it into a thick paste. The assumption of 2 equivs. of water converts the particles of the powder into a porous net-work of gypsum crystals, which enclose the remainder of the water mechanically in their interstices, and give it out again on drying in the air. The freshly-set, moist gypsum, is at first very soft, but acquires its full hardness on drying; those portions which have been dissolved by the excess of water, are then gradually deposited, and cement the already solidified particles more strongly together. Solidified gypsum has by no means the degree of hardness of the ordinary stones, and although somewhat sonorous, is yet easily scratched with the nail. The property of setting with a large excess of water is a very important property in gypsum, as it can only fill the minute indentures of the mould in the state of a liquid paste. For very fine casts of medallions, &c., the paste must be more limpid than for larger objects. The thinner, however, the paste that is employed, the more porous and loose are the casts which it yields. This useful hint is of great importance in practice. The necessary degree of porosity for the moulds employed in the potteries, for instance, is attained with certainty by using a definite known quantity of water. The quantity of water, however, must be adapted to the variable quality of the gypsum, and depends very much upon the temperature at which it has been calcined. The time required for hardening is also effected by the same circumstances. As a general rule, this is lengthened, in gypsum that has been burnt at the same temperature, by the foreign substances (carbonate of lime, &c.) which it contains, and by the increased dilution of the paste. Mixed with a large excess of water, the particles of gypsum combine with the proper quantity, but are incapable of binding or setting. Burnt gypsum also loses its property of hardening with water, when it has been exposed for a length of time to a moist atmosphere. If properly-set gypsum is immersed in water, it becomes softer and softer, until at last it falls to pieces.

It is well known, that in multiplying works of art, gypsum itself is cast in plaster moulds. In order to prevent the cast from adhering to the mould, the latter is saturated with oil, or better, with a mixture of soap and oil, without, however, allowing any portions of the mixture to protrude beyond the surface of the gypsum. The required density and hardness of the cast, the longer or shorter time in which it is desirable that it should set, the degree of fineness in the object cast, and lastly, the nature of the gypsum itself, must all be taken into consideration in regulating the degree of liquidity or the consistency of the paste.

Making the Moulds.—In imitating works of art by the aid of gypsum, the first object is the preparation of the moulds. This is not attended with any difficulty when the object is flat and only one surface is to be moulded, as is the case with many medallions, coins,

&c., where no rentrant angles impede the removal of the mould. These moulds are made in one piece.

The difficulty is very much increased when the form of the object to be moulded, renders it impossible to remove the entire mould without damage or injury, as is the case with statues, &c. In all these cases, the mould must be prepared from as many pieces as can be each separately and with ease removed from the model. All these pieces together then compose the mould. There are three ways of making these moulds.

The separate parts are either moulded as so many different subjects, and these different pieces are then fitted together by hand, (cutting the edges, &c.,) without reference to the model, so as to form one entire mould.

Or the entire model is covered with a mass of gypsum which is then broken into pieces and separated. In order to do this with greater regularity, notches are cut into the plaster from the outer surface to within a few lines of the model. The separate pieces then crack in the direction of these notches. The first plan requires too much skill in the operator, and the casts are seldom true; the second, on the contrary, affords exceedingly true castings, but the jagged edges soon crumble away after the first cast has been taken, and give rise to extensive sutures. For this reason the only method in which numerous true casts can be obtained from the same mould is when:

Lastly, the mould is cast in pieces upon the model. A border of clay is placed round a portion of the model and into this enclosed space plaster is poured. The solidified piece is then removed, the edges are cut slanting in a direction towards the model, and small round holes are made in them; it is then greased and again placed upon the same part of the model, and a second piece is cast at the side of it. The round holes in the old piece are now filled by projections in the new one, and by means of these, the two pieces can be accurately applied, the one to the other. This operation is repeated upon a third part of the model, and so on until the whole has been moulded. A mould prepared in this manner will yield sixty or more good casts before the finer and sharper parts become blunted.

Most casts, particularly the larger ones, are generally made hollow, in order to spare material and render them lighter. A very thin paste is first introduced into the mould which is swung backwards and forwards until this first outside coat of the cast has set; the necessary quantity of thicker paste is then introduced to give more solidity to the cast. For very delicate objects and fine moulds it is better to apply a very thin gypsum paste in the first instance with a brush, and then pour in the more solid paste. This should be done with finely engraved coins, &c. Admirable casts of natural leaves can be obtained, when these are properly supported and the gypsum is first applied with a brush, and as soon as the first layer has become stiff, a second very thick coat of plaster is applied. A layer applied with

the brush in this manner is very desirable, as it excludes the possibility of air-bubbles settling between the mould and the casting.

In casting objects in precisely their original dimensions, it must not be overlooked, that gypsum expands about 1 per cent. in hardening. This expansion is of course compensated when a gypsum cast is again taken from a gypsum mould, which is not the case when the cast is composed of metal.

In places like Paris, gypsum is extensively used as mortar for covering walls. While slaked lime is essentially improved by the addition of sand, the contrary is the case with gypsum. It will not bear more than from $\frac{1}{3}$ to $\frac{1}{2}$ of sand or brick-dust, and hardens very much less quickly and well than in the pure unmixed state.

Stucco.—Gypsum applied to walls can be easily ground, polished, or colored, and is often made to resemble marble in the most striking manner. Coatings of this kind are known by the name of *stucco*, in which term architectural ornaments composed of gypsum are also included.

In coating a wall with stucco, a coarser kind of gypsum is employed as ground, upon which the finer quality, mixed with a solution of glue, is applied. That proper time may be allowed for plastering, the stucco must be so mixed that it will harden in from twenty to thirty minutes. With the aid of the glue, the surface becomes sufficiently hard to bear leveling with pumice-stone. The even surface is then rubbed over with gypsum paste, prepared with a stronger solution of glue, in order to fill all the pores and inequalities, and if necessary, this process is repeated. When fully dry, the surface is hard enough to bear polishing with tripoli and linen rubbers. In the meantime, the stucco is saturated with linseed-oil by the aid of a brush. Any color can be produced by mixing earthy pigments with the solution of glue and rubbing this up with the stucco. When layers of different colored gypsum are laid one upon another in this manner, they will present a ribboned appearance in section; and when the layers are intermingled with each other, the mass assumes a marbled surface. Indeed, colored striped marbles are simply the section of layers overlying one another in this manner.

Hardening, or Setting.—A variety of methods have been sought to remedy the softness of gypsum casts, and render them less liable to be injured by scratching, &c. The different methods are classed together under what is termed the *hardening*.

An observation of Gay-Lussac's is worthy of notice in the first place, which is, that, under like circumstances, the hardest crude gypsum yields also, after calcination, the hardest casts, and the converse. The chief hardening methods and substances, after glue, as applied to stucco, are the following:

According to Tissot, burnt gypsum, after it has set and become hard, should be repeatedly immersed in water, and dried each time. This operation appears to be a simple means of increasing the cementation of the particles by crystalization.

A much better and more interesting process is that first proposed

by Pauware, and improved by Greenwood, which consists in hardening gypsum by means of alum, upon which subject Elsner has lately made some important observations. There are two methods of hardening by means of alum, which must be distinguished from each other.

The one plan is to treat the finished castings with a solution of alum. A large bust was placed, for the space of a month, in a solution of alum, free from iron, in from 12 to 13 parts of water, at 15° C. (59° F.), and at the expiration of this time it was wiped and dried in a current of warm air. It was now no longer capable of being scratched with the nail, nor did it soil the fingers, as was the case previous to immersion. Even powerful strokes with an iron hammer were incapable of breaking it. These advantages were, however, accompanied by a gray spotted appearance, and a tendency to be affected by moisture. Casts which have been treated in this manner, when immersed in cold water, become so soft that they easily take the impression of the finger.

The second method of hardening with alum consists in treating the lumps of gypsum, as they leave the kiln, with a solution of alum, or powdered gypsum is triturated with a solution of this kind, and these are then again exposed in the gypsum kiln, or in a crucible, to a red heat. A steady uniform temperature is very essential in this operation. Gypsum, burnt a second time in this manner, with alum, possesses a dull, milk-white, or slightly cream-colored appearance, and is easily pulverized. When the heat has been excessive, the blocks become as hard as stone on the edges, and are very difficultly reduced to powder; they are, indeed, dead-burnt. A properly burnt composition of gypsum and alum, solidifies after being pulverized, quite as readily as gypsum alone. If the gypsum-powder is mixed with water, the water enters into combination, but the product is not remarkably hard; the mixture of alum and gypsum requires to be mixed with a solution of alum, containing from $\frac{1}{12}$ to $\frac{1}{13}$ of alum, in order fully to develop this property. Plaster casts remain longer moist when the gypsum has been thus prepared, but acquire a degree of hardness equal to that of alabaster or marble, and are translucent like those substances, in the less thick parts and angles. Thick plates can scarcely be broken with the hammer. The surface is white, with a tint of cream color, and takes a good polish. Exposure to the weather during whole months in winter does not injure objects prepared in this manner, or diminish their hardness in the least. The surface may be cleansed with wet cloths without damage. Immersion in cold, and even several hours' exposure to *boiling* water, does not impair the hardness of the substance in the slightest degree (Elsner).

It is to be regretted that no chemical investigation of the process concerned in the hardening of gypsum, by means of alum, has been published.

There exists, perhaps, a similar affinity between sulphate of lime

and sulphate of alumina, as has been shown to be exerted between the latter and sulphate of magnesia.

Another property of gypsum, which may possibly be in some way connected with these phenomena, may, lastly, be noticed. In the former part of this section it was pointed out, that one equivalent of the water contained in gypsum was saline water, or such as can be replaced by a saline compound. The combination of a salt with gypsum gives rise to solidification, as was the case with water, but no greater degree of hardness is thus communicated to the gypsum. Solutions of carbonate, sulphate, and silicate of potash, produce much more rapid solidification than water; a solution of tartrate of potash and soda (Seignette salt) causes instantaneous solidification.

The hardened mass has the appearance of ordinary gypsum, but it possesses the property of again hardening, when it is re-pulverized and mixed with a solution of a salt of potash. Bicarbonate of potash is decomposed by gypsum, with the evolution of carbonic acid; caustic potash decomposes a portion of the gypsum, and in both cases solidification ensues. Chlorate and nitrate of potash and the salts of soda do not produce the same effect.

Another mode of hardening gypsum was stated at page 150, in connection with soluble glass.

MAGNESIA.

Sources of Magnesia.—But few of the compounds of magnesia are manufactured upon a large scale, and those that are so, are generally derived from the waste products of some other manufacture. Thus the mother-liquors from the salt works (vol. i. p. 246–260) afford a source of chloride of magnesium which can be converted into any of the preparations into which this base enters. The waste liquors from the alum-works also afford sulphate of magnesia or Epsom salts, as was stated at pages 163 and 172. But the chief source of magnesia is found in the magnesian limestones (Zechstein of the Germans) which abound in this and in most other countries, and the chemical composition of several of which has been stated in the tables at page 351, and the following. To these we may add some analyses of foreign magnesian limestones lately executed: and a series of French calcareo-carbonates of magnesia analyzed by Berthier.

MAGNESIAN LIMESTONE (DOLOMITE).

	Norway.	Tharand.	Tyrol.	Schnee-berg.	Koloso-enck.	Bohemia.	
Carbonate of lime	55.88	54.76	54.50	52.64	85.84	61.30	77.63
Carbonate of magnesia	40.47	42.10	44.48	35.80	10.39	32.20	18.77
Carbonate of iron	2.81	4.19	3.73	12.41	5.53	6.27	3.67
Carbonate of manganese	—	—	—	0.34	—	—	—
	99.16	101.05	102.71	101.19	101.76	99.77	100.07
	Scheerer.	Kuhn.					

CALCAREO-CARBONATES OF MAGNESIA.

	1 Briene.	2 Namar.	3 Bruniquel.	4 Namar.	5 Bourbonne	6 Bourbonne.	7 Estoron.	8 Schirnech.
Lime	44.0	37.6	34.2	29.1	29.2	30.0	10.7	29.5
Magnesia	8.4	13.6	16.2	21.0	21.2	22.4	7.7	20.0
Protoxide of iron	—	1.8	—	1.2	—	—	0.8	1.3
Protoxide of manganese	—	—	—	—	—	—	0.3	—
Carbonic acid and water	40.6	45.6	44.0	46.7	44.6	47.0	18.6	46.4
Foreign matter	7.0	0.4	5.2	2.0	5.0	0.6	61.9	2.2
	100.0	99.0	99.6	100.0	100.0	100.0	100.0	99.4

The limestones under 4, 5, 6, 7, and 8, are obviously composed of 1 equiv. of carbonate of lime to 1 equiv. of carbonate of magnesia. No. 1 is a compound of 4 equivs. carbonate of lime to 1 equiv. of carbonate of magnesia. No. 2, of 2 equivs. of carbonate of lime to 1 of carbonate of magnesia; and No. 3, of 3 equivs. of carbonate of lime to 2 equivs. of carbonate of magnesia.

In England, the magnesian limestone lies immediately over the conglomerate or sandstone bed which covers the coal-measures; beginning at Tynemouth, it extends with little or no interval as far as Nottingham, or about 147 miles. In the course of this extent, it varies very considerably in appearance, but is generally a moderately compact limestone of a yellow color, and consists of equal equivalents of carbonate of lime and magnesia.

SULPHATE OF MAGNESIA.

From Natural Solutions.—This salt is found in sea water, in several salt springs, and even in ordinary well water. The oldest source whence it is procured is that of Epsom, in Surrey, from whence it acquired the name of "Epsom Salts." It also occurs in the springs at Saidschütz, in Bohemia, and as an efflorescence in many localities, termed "Hair Salts" by mineralogists.

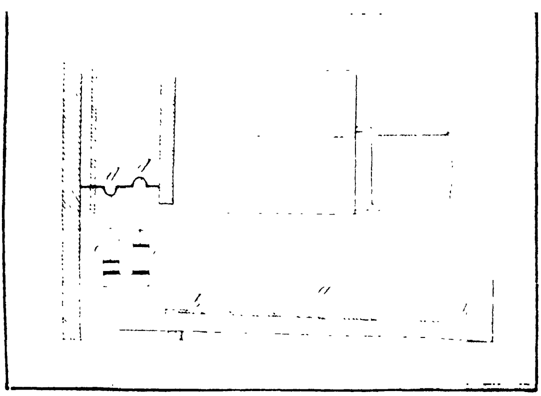
It is procured from these bitter springs by simple evaporation and crystalization, but in such cases it is always contaminated with some chloride of magnesium. The same simple process is employed in some places to obtain it from the mother-ley after the common salt has been extracted from sea water, in which cases the sulphate of soda and chloride of magnesia are mutually decomposed, yielding common salt and sulphate of magnesia.

From Shale.—It is also obtained in the neighborhood of Genoa from a shale containing magnesia, and the sulphurets of iron and copper. The shale is roasted and exposed to the action of the weather, which facilitates the oxidation of the sulphurets. The magnesia abstracts a considerable portion of the sulphuric acid so formed, and the whole mass is then lixiviated. The copper is precipitated from the liquid by pieces of iron, and the iron is afterwards thrown down by the addi-

tion of milk of lime. The sulphate of magnesia is procured by boiling down the residual liquors and crystalization. The sulphate of magnesia obtained in this way is, however, never free from the sulphates of iron and copper.

From Magnesian Limestone.—In this country, the sulphate is sometimes manufactured directly from magnesian limestone and sulphuric acid, in conjunction with other products. The carbonic acid produced by the action of the sulphuric acid is employed in the manufacture of bicarbonate of soda, already described at p. 296, vol. i., while the mixed sulphates of lime and magnesia are thrown into large wooden vessels *A*, Fig. 244, which are fitted with a false bottom *b b*. Water is now poured upon the thick mass and drawn through by the action of a pair of pumps *c c*, worked from an engine shaft in any convenient manner, as shown at *d d*. In this way, the whole of the sulphate of magnesia is extracted with the least expenditure of water; and the solution, after being pumped into a reservoir, is allowed to filter through layers of sandstone and charcoal to render it clear and bright, as shown in the sketch, Fig. 244, at *B*. The solution is now concen-

Fig. 244.



trated by evaporation, and made to crystalize as rapidly as possible, in shallow wooden troughs lined with lead, in order that the crystals may be as small as possible to meet the prejudice of the trade in this respect. The sulphate of lime left on the filter or false bottom *b b*, is worked up in the manufacture of Venetian red.

The process, however, which is more generally pursued is as follows:

Magnesian limestone is calcined in an ordinary lime-kiln, and repeatedly washed with water to remove as much of the lime as possible. The extent to which this is carried may be inferred from the following analyses of a sample of limestone in its natural state, and after it had been calcined and washed:

NATURAL.		WASHED.	
Carbonic acid, &c. - -	47.12	Water, &c. - - - - -	32.51
Lime - - - - - - -	27.49	Lime - - - - - -	7.34
Magnesia - - - - -	22.22	Magnesia - - - - -	44.41
Insoluble matter, alumina, &c.	3.17	Insoluble matter, alumina, &c.	15.74
	100.00		100.00

(Richardson.)

The limestone selected by the manufacturer for this purpose is soft, and similar to that known as *flexible;* such samples as have the appearance shown in the sketch (Fig. 245) do not usually contain so much magnesia.

Fig. 245.

From refuse Alum-liquors.—In the manufacture of alum as conducted near Whitly, the "salts'-mothers" contain in the gallon:

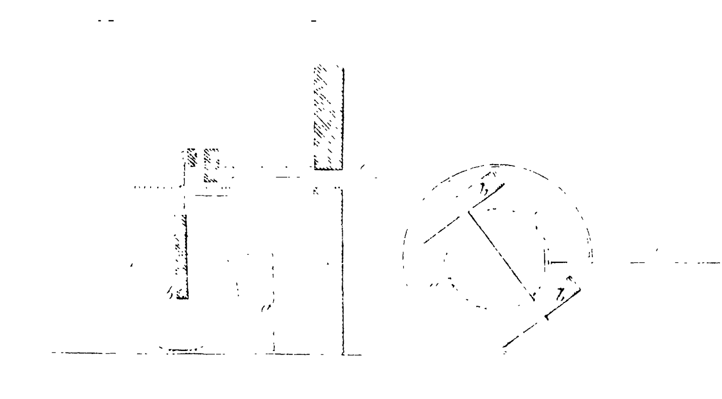
Sulphuric acid (free) - - - - -	2697.61
Sulphate of magnesia - - - - -	8910.40
Sulphate of alumina - - - - -	852.24
Sulphate of potash - - - - -	3693.32
Sulphate of manganese - - - - -	106.06
Sulphate of nickel and cobalt - - -	traces
Sulphate of iron - - - - -	3026.67
	grs. 19286.30 (Richardson)

which by crystalization produces a crude sulphate of magnesia, called "Rough Epsoms" which has the following composition:

Sulphuric acid	32.26
Magnesia	15.35
Protoxide of iron	1.73
Oxides of nickel and cobalt	0.12
Lime	0.09
Alumina	1.33
Potash	0.83
Water	48.29
	100.00 (Richardson.)

These rough Epsoms are mixed with the washed magnesian lime in such proportions that all the sulphuric acid, except that in combination with the potash and magnesia, is taken up by the free magnesia and lime. The mixture is then calcined in an ordinary reverberatory furnace, at a dull red heat, which assists the transfer of the sulphuric acid, and raises the metals to a higher degree of oxidation, thereby ensuring their insolubility. The calcined product is afterwards thrown into a large circular cistern *a*, Fig. 246, filled with water, and in

Fig. 246.



which a pair of edge-stones *b b*, is made to revolve by suitable machinery *c c*. By this arrangement, the large pieces are ground to powder, while the agitation produced by the motion of the edge-stones facilitates the solution of the sulphate of magnesia.

The sulphate of magnesia liquor is subsequently clarified in the manner previously described, and crystalized in the usual shallow pans. When the liquid has drained off from the crystals, they are removed to a stove and dried at a low temperature. In this dry state, they are thrown into a species of temse, which reduces still further the size of the crystals, and renders the whole of a more uniform appearance.

From Bicarbonate of Magnesia.—Mr. Pattinson has also patented the application of his bicarbonate of magnesia solution for the production of sulphate of magnesia, which he effects by employing either sulphuric acid or its equivalent quantity of sulphate of iron, heating to the boiling point, and separating, in the latter case, the precipitated carbonate of iron by subsidence, and then crystalizing.

From native Carbonate of Magnesia.—Mr. Chance has lately imported a very pure, natural carbonate of magnesia from the Mediterranean, to which he adds sulphuric acid, and proceeds in the usual way for the production of this sulphate; and having, it is understood, secured the entire produce of the mine, he is likely to become a formidable competitor to the other manufacturers.

Another article is manufactured to some extent which requires a passing notice here, viz., what are termed "Mock Epsoms," which is simply sulphate of soda crystalized very rapidly in shallow vessels for the purpose of adulterating the genuine article.

The sulphate of magnesia crystalizes in right prisms, which at 60° Fahr. are soluble in their own weight of water. When exposed to the air, they effloresce and are reduced to powder. This salt has the well-known intensely bitter taste; and is composed of

Magnesia - - - -	16.26
Sulphuric acid - - -	32.52
Water - - - -	51.22
	100.00

CARBONATE OF MAGNESIA.

Native.—This substance occurs in nature, and is known under the name of magnesite, of which the formula is $MgOCO_2+3HO$; but this form, under which it is sold in commerce, is really a subcarbonate of which the composition varies according to the following formulæ:

$$4MgOCO_2 + MgOHO$$
$$3MgOCO_2 + MgOHO$$
$$2MgOCO_2 + MgOHO$$

and is usually called *magnesia* or *magnesia alba.*

From the Sulphate.—It is sometimes manufactured from Epsoms, or sulphate of magnesia, and from the chloride of magnesium contained in the mother-ley of common salt. In the latter case, the carbonate of magnesia is precipitated by the addition of the crude carbonate of ammonia, while sal ammoniac remains in solution. Dolomite is also employed for the same purpose, when sufficiently pure, by which the carbonate of lime becomes converted into chloride of calcium, leaving the carbonate of magnesia behind as an insoluble powder.

In this country it has been customary to employ the sulphate of

magnesia, but this process will be ultimately superseded by that patented by Mr. Pattinson, to be described hereafter. The sulphate of magnesia is dissolved alone in boiling water, and about $\frac{1}{8}$ more carbonate of soda in another vessel. The two hot solutions are then run together into large wooden vessels, while a workman keeps the whole in continual agitation, for some time; the mixture is afterwards allowed to remain at rest for an hour or so to permit the precipitated carbonate of magnesia to subside. When this deposit has taken place, the fine precipitate is repeatedly washed with pure water to remove all traces of the sulphate of soda formed by the double decomposition of the two salts. The carbonate of magnesia is then allowed to drain, until it acquires sufficient consistency to be formed into small pieces in the shape of parallelopipedons, and then dried on wooden shelves in a stove at a low temperature.

The carbonate of magnesia, so prepared, is heavier than that manufactured in the cold, and contains more hydrate of magnesia, a portion of carbonic acid escaping during the agitation, in consequence of the high temperature of the liquid.

From Magnesian Limestone.—Mr. Pattinson's process consists in exposing finely ground and sifted magnesian limestone to a red heat in an iron retort or reverberatory furnace for two or three hours, by which he deprives the magnesia of its carbonic acid, and renders it soluble in water impregnated with the same acid. About 120 lbs. of this calcined magnesian limestone are then introduced into a strong iron cylinder lined with lead, and fitted with an agitator also covered with lead. A quantity of carbonic acid gas is now pumped into the cylinder, while the contents are kept in constant motion by the agitator, until absorption ceases under a pressure of five atmospheres. The whole is allowed to remain undisturbed for three or four hours, when the contents are run off into a cistern and allowed to subside. The clear supernatant liquid is a solution of carbonate of magnesia in water, holding carbonic acid in excess, from which the carbonate of magnesia may be obtained by boiling to expel the excess of carbonic acid, or by evaporation to dryness. In either case the subsequent treatment is the same as described above.

Mr. Pattinson modifies the process by employing the hydrate of lime and magnesia obtained by slaking thoroughly burnt magnesian limestone, which, however, requires a larger quantity of carbonic acid. He also proposes to substitute for the above the calcined magnesian lime, from which part of the lime has been removed by washing, or a rough hydrate of magnesia obtained by dissolving magnesian limestone in muriatic acid and treating this solution, or a solution of chloride of magnesium in the form of *bittern*, with its equivalent quantity of hydrate of lime.

The carbonate of magnesia manufactured as above, is a beautiful white substance, very light and without either taste or smell. It dissolves in 2,500 parts of cold, and in 9,000 parts of hot water, and is generally composed of

Magnesia - -	53.60
Carbonic acid -	41.73
Water - - -	4.67
	100.00

It is employed in medicine, and for the preparation of pure magnesia by simple calcination. E. Davy has proposed to use it in baking bread for the purpose of rendering this article of food lighter, which effect is most probably produced by the action of the acetic acid in the dough, disengaging the carbonic acid.

SILICATE OF MAGNESIA.

Under this term, a number of natural productions are included which are of various application in the arts and manufactures, but in the preparation of which no particular process is employed. It will, therefore, be simply necessary to give their composition, and the purposes to which they are applied.

a. Steatite or soap-stone.

This substance is known also under the more familiar names of Spanish or Venetian chalk. Its composition is as follows:

	North America.	Sala Sweden.	Cornwall.	China.
Silica - - -	50.60	63.13	45.00	66.53
Magnesia - -	28.83	34.30	24.75	33.42
Alumina - -	0.15	"	9.25	"
Oxide of iron -	2.59	2.27	1.00	trace.
Oxide of manganese	1.10	"	"	"
Water - -	15.00	"	18.00	"
	98.27	99.70	98.00	99.53
	Dewey.	Lychnell.	Klaproth.	

	English.	Sharam, Norway.	Hofgastein.	Miask.
Silica - - - -	46.8	32.03	57.83	25.60
Alumina - - -	8.0	12.52	7.06	22.21
Ox. iron - - -	0.4	4.48	9.45	5.00
Magnesia - - -	33.3	37.52	25.58	30.96
Lime - - - -	0.7	"	"	"
Water - - - -	11.0	16.19	"	13.43
	100.2	102.74	99.92	97.20
	Svanberg.	Hochstetter.	Wornum.	Hermann.

It is employed in polishing articles made of serpentine, marble, gypsum and plate-glass. When levigated, it is used as an ingredient of rouge. It is also sometimes used as a substitute for grease in the axles of carriages. It is further employed for sketching in outline on silk, linen and glass; as crayon; for painting on glass and for re-

moving stains in woolen and silk goods. It has also been added in some cases to the materials for porcelain, to improve the transparency, but it renders the mass more brittle. The apparatus employed for the production of chlorine is occasionally manufactured from this material, as it resists the corrosive action of this gas.

b. Meerschaum.

This form of silicate of magnesia, is employed in manufacturing the celebrated tobacco-pipes known under this name, and its composition is as follows:

	Levant.	Madrid.	Natolia.
Silica - - - - -	60.87	53.80	42.00
Magnesia - - -	27.80	23.80	30.50
Lime - - - - -	"	"	2.30
Alumina - - -	0.09	1.20	2.00
Ox. of iron - - -		"	
Water - - - - -	11.29	20.00	23.00
	100.05	98.80	99.30
	Lychnell.	Berthier.	Thomson.

MEERSCHAUM FROM MOROCCO, ANALYZED BY DAMOUR.

Silica - - - - - -	55.00
Magnesia - - - - - -	28.00
Alumina - - - - - -	1.20
Ox. of iron - - - - -	1.40
Lime - - - - - -	1.10
Potash - - - - - -	.52
Water - - - - - -	10.35
Sand - - - - - -	1.50
	98.98

Dobereiner has published an interesting paper on the artificial production of this material in the Journal für Praktische Chemie, vol. xxii., p. 157.

c. Asbestos.

This material is of frequent use in the laboratory, and in the manufacture of various articles destined to resist the action of fire, such as lamp-wicks, &c. Its composition is as follows:

	Kobell.	Richardson.	Thomson.
Silica - - - - -	43.50	43.35	40.95
Magnesia - - -	40.00	31.85	34.70
Oxide of iron - -	2.08	10.90	10.05
Alumina - - -	.40		1.50
Water - - - - -	13.80	7.05	12.60
	99.87	98.15	98.80

BARYTES.

The salts of barytes employed in the arts, are confined to the carbonate and sulphate, (with the exception perhaps of the chloride and nitrate so universally employed in the laboratory as tests for the presence of sulphuric acid.)

Carbonate of Barytes.—Carbonate of barytes (witherite) is found in tolerable abundance in Wales, Lancashire, and several parts of England; but very little of it is sufficiently pure for general purposes, owing to its being mixed with sulphate of barytes, sulphate and carbonate of lime, peroxide of iron, and in some samples, especially those of waxy appearance, carbonate of iron, sometimes to the extent of several per cent.

The native carbonate has been analyzed with the following results:

ANGLEZARK IN LANCASHIRE.

Barytes	78	79·7	78·6
Carbonic acid	22	20·0	21·4
Water	"	0·3	"
	100	100	100
	Klaproth.	Bucholz.	Withering.

BARYTO-CALCITE FROM ALSTON MOOR, CUMBERLAND.

Carbonate of barytes	65·9	62·20
Carbonate of lime	33·6	31·65
Sulphate of barytes	"	0·30
Peroxide of iron	"	0·85
Water and volatile matter	"	3·45
	99·5	98·45
	Children.	Richardson.

The use to which the native carbonate has been applied is the preparation of the various salts of barytes, which are made by saturating the respective acids with the powdered native carbonate.

An artificial carbonate is prepared by a process discovered and patented by the late Mr. Woolrich of Birmingham, and now carried on by his son, Mr. J. S. Woolrich, who has lately succeeded in introducing it into the manufacture of plate and flint glass with considerable success, as a cheap substitute for part of the alkali. The barytes fuses with an equivalent of silica, and forms a silicate of barytes, which mixes with the other silicates. The glass possesses the properties of the best plate and flint glass. It is also used in the manufacture of porcelain, jasper, &c. The artificial carbonate is prepared by heating the crude native sulphate of barytes (cawk) in a peculiar furnace with carbonaceous matter, until the following interchange of elements takes place:

		Equivalent.	
Sulphate of barytes	Barium	1	2 equivalents of carbonic acid gas.
	Oxygen	1	
	Sulphur	1	
	Oxygen	3	1 equiv. of sulphuret of barium.
	Carbon	2	

The sulphuret of barium is dissolved in water, and the two equivalents of carbonic acid gas are passed through it in such a manner as to convert the sulphuret of barium, with a portion of the water, into sulphuretted hydrogen gas, and carbonate of barytes; or this process might be modified by first washing out all impurities with the waste muriatic acid of the alkali works, then treating the sulphate as practiced by Mr. Woolrich; but instead of dissolving it in water, to expose the solid sulphuret in a moist state to the action of carbonic acid, by which means the sulphuretted hydrogen might be more easily collected and burnt to produce sulphuric acid in a vitriol chamber.

Considerable attention is required to prevent the formation of sulphite, hyposulphite, and some compounds of these with sulphur and with barytes, the presence of which would injure the quality of the carbonate, especially for the purpose of glass-making. No iron must, of course, be present in the prepared carbonate. When washed with pure water, and dried, it is a fine, white, impalpable powder; and the low price at which it is sold, gives it a preference over the native carbonate.

It is composed of

1 equiv. barytes, or	77.66
1 " carbonic acid,	22.41
	100.00

The carbonate, like all the other salts of barytes, is poisonous. It is scarcely soluble in cold or boiling water, but is dissolved by free carbonic acid in the water. Its sp. gr. is 4·33.

Sulphate of Barytes (*heavy spar*).—Sulphate of barytes is found in considerable abundance in Scotland, Wales, and many parts of England, and is employed as a pigment, and also for the purpose of adulteration.

The following is the composition of the native sulphate from different localities:

	Freiberg.	Peggau.	Neu-Leiningen.	Nutfield, Surrey.	Klausthal.
	Klaproth.			Stromeyer.	Jordan.
Sulphate of barytes	97.50	90.0	99.0	99.3762	86.0
Sulphate of strontia	0.85	—	—	—	6.75
Silica	0.8	10.0	—	—	5.75
Water	0.7	—	—	0.0667	0.375
Oxide of iron	—	—	trace	0.0506	—
	99.85	100.0	99.0	99.4935	98.875

The pigment, known under the name of "permanent white," is made by precipitating the sulphate from a soluble salt of barytes, such as the chloride, by means of sulphuric acid or a soluble sulphate, which, when washed and dried, forms a beautiful white powder, that is not acted upon by sulphuretted hydrogen gas. It is to this property that it owes its superiority over white lead as a water-color, the action of sulphuretted hydrogen upon the latter turning it brown or black, while the barytes retains its pristine color. It, however, can only be employed as a water-color, for oils destroy its whiteness, and render it nearly transparent, while white lead makes an opaque mixture, said by the trade to possess "body." The sulphate of barytes employed for the purposes of adulteration is made by levigating the whitest varieties of the native sulphate, and afterwards bleaching it, by boiling with dilute sulphuric or muriatic acid, for the purpose of dissolving out any iron which it may contain. It is then well washed and dried, and forms a dense white powder. Some of the native sulphate is sufficiently free from impurities and coloring matter as not to require the bleaching process. The sulphate preferred by the manufacturer on account of the facility of reducing it to powder, is that which is white and soft, possessing little or no crystaline structure.

The adulteration of white lead is carried on to a considerable extent with this substance, but not in this country, where it is only employed in the manufacture of the inferior qualities of white paint. Some of the samples of white lead sold on the continent, contain three-fourths of this prepared sulphate of barytes, the presence of which can easily be detected by dissolving out all the carbonate of lead, by dilute acetic acid. The sulphate of barytes being unacted upon, can be washed, and the quantity ascertained by weighing.

A sample from Belgium contained:

White lead - - -	15.82
Sulphate barytes - -	84.07
	99.89 Richardson.

STRONTIA.

Source of Strontia.—The nitrate of this earth is the only salt made upon a manufacturing scale, and its application is limited to the purposes of the fire-work makers in producing the brilliant red or purple fires. It is prepared from the native sulphate (coelestine), which occurs in compact masses in the neighborhood of Paris, crystalized at Jena in Saxony, at Bristol, Edinburgh, and in Pennsylvania. The finest specimens, however, are found associated with native sulphur in Sicily.

The following is the composition of the native sulphate from different localities:

	Klaproth.		Dornburg, near Jena. Stromeyer.		Bristol. Thomson.	Sicily. Thomson.
Strontia	58	. . . . .	56.2650		98.353	93.68
Sulphuric acid	42	. . . . .	42.9524			
Oxide of iron	trace	Protoxide of iron	0.0254		0.374	—
		Alumina	0.0508			
	100	Carbonate of lime	0.1016	SO_3CaO	1.073	1.02
		Bituminous matter and water	0.1056		0.200	0.30
			99.5006		100.000	100.00

	Canada.	Süntel, near Münder.	Dehrself. near Alfeld. in Hanover.	Girgenti.	Fassathal.	Dornburg, near Jena.
Strontia	35.724	55.1835	97.601	56.3546	92.1454	54.731
Sulphuric acid	40.202	42.7385		43.0757		43.756
Oxide of iron	.588	0.0403	oxide 0.616	hyd. ox. 0.0298	oxide 0.5000	—
Sulphate of barytes	23.059 Baryta	0.8603	0.975	—	1.8750	—
Carbonate of lime	—	0.0153	—	0.0905	and sulph. 1.8333	1.416
Lime	—	0.3104	—	—	—	—
Water	.720	0.0497	0.218	0.1788	—	—
Silica	—	—	0.107	—	1.0000	—
	100.293	99.198	99 577	89.7294	97.3537	99.903 Madrell.

Manufacture of Nitrate of Strontia.—The native sulphate from Bristol is employed in the manufacture of the nitrate in this country; it is ground in a mill to a fine powder, mixed with charcoal or small coal, and roasted in a reverberatory furnace, until the whole is converted into sulphuret of strontium. The chemical process is the same as was illustrated above with the sulphate of barytes. The roasted mass is boiled and lixiviated with water in cast-iron boilers, until the whole of the sulphuret is dissolved. The sulphuret is then converted into nitrate by the addition of *dilute* nitric acid, sulphuretted hydrogen gas being evolved. An excess of nitric acid must be avoided, as the solution cannot otherwise be concentrated in iron vessels, which it is desirable to use for the sake of economy. When sufficiently concentrated, the liquor is transferred to earthenware pans, where it is rendered sensibly acid by the addition of more nitric acid, to crystalize. The crystals are formed more readily and of larger size from an acid than from a neutral solution. During the cooling of the solution of nitrate of strontia, flashes of light have been observed in the dark, and it appeared to Mr. Scanlan, to whom we are indebted for this account of the manufacture, as if light were evolved at the birth of every new crystal.

Nitrate of strontia crystalizes in octahedrons, or sometimes in irregular prisms, which are anhydrous. Under other circumstances, however, large octahedrons are obtained, containing 30 per cent. of water of crystalization, and these are preferred by the fire-work makers, as, by efflorescence, the salt can be obtained in the state of a fine powder, which mixes better with the chlorate of potash and charcoal in

the composition for red fire. Heated to redness, this salt melts in its water of crystalization, evolves oxygen, nitrogen, and nitrous acid, leaving pure strontia as residue. The salt possesses a cooling, sharp taste, it is soluble in 5 parts of cold, and in ½ of boiling water. It is also soluble in alcohol. The anhydrous salt contains 48·9 parts of strontia to 51·1 of nitric acid.

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THE END.

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